This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

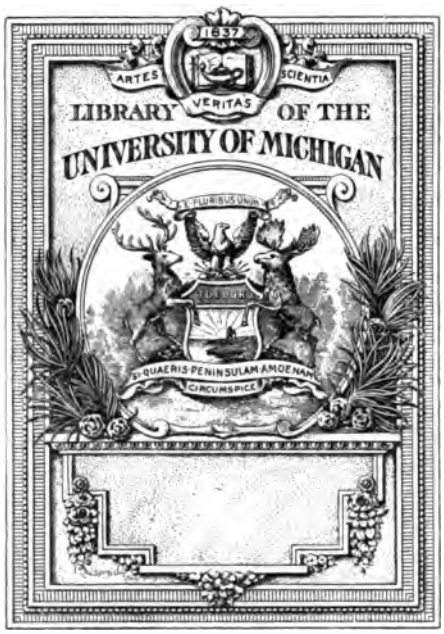
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



THE GIFT OF
Supt. of documents

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETINS

Nos. 331-335

WASHINGTON

GOVERNMENT PRINTING OFFICE

1908

CONTENTS

Geological Survey, bulletin 331; Portland cement mortars and their constituent materials.
same, 332; Report of U. S. fuel-testing plant at St. Louis, Mo.
same, 333; Coal-mine accidents: their causes and prevention.
same, 334; Burning of coal without smoke in boiler plants.
same, 335; Geology and mineral resources of Controller Bay region, Alaska.

208679

Bulletin No. 331 Series R, Structural Materials, 3

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PORTLAND CEMENT MORTARS AND THEIR CONSTITUENT MATERIALS

RESULTS OF TESTS

MADE AT THE

STRUCTURAL-MATERIALS TESTING LABORATORIES
FOREST PARK, ST. LOUIS, MO., 1905-1907

BY

RICHARD L. HUMPHREY

AND

WILLIAM JORDAN, JR.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

CONTENTS.

	Page.
Introduction	1
General statement	7
Nature and extent of the investigations	7
Scope of the work	7
Register numbers	8
Outline of tests	8
Tests of strength	8
Storage	8
Tension	8
Compression	8
Transverse	9
Results of tests	9
Tests of cement	9
Individual brands and typical Portland cement	9
Acknowledgment of donations	9
Method of tests	9
Selection of samples	10
Mixing of typical Portland cement	10
Chemical analyses	10
Physical determinations	12
Method	12
Specific gravity	22
Time of setting	22
Fineness	22
Constancy of volume	22
Tensile strength	22
Effect of age on tensile strength	23
Compressive strength	24
Effect of age on compressive strength	25
Percentage of gain in strength	26
Strength tests of typical Portland cement used in tests of mortars of sand, of gravel screenings, and of stone	34
Method of tests	34
Tensile strength	35
Compressive strength	37
Transverse strength	39
Lapse of time between first and last molding	42
Sands and sand mortars	42
Acknowledgment of donations	42
Method of collection	42
Descriptions of sands	43

Sands and sand mortars—Continued. Page.
Physical tests of sands 53
Method 53
Granularmetric analyses 53
Granularmetric curves 53
Comparison between measured and computed voids 55
Uniformity coefficient 55
Physical tests of sand mortars 56
Method 56
Tensile strength 57
Compressive strength 57
Transverse strength 57
Sumary of sand-mortar tests 57
Density 58
Gravel-screenings mortars 79
Acknowledgment of donations 79
Method of collection 80
Descriptions of gravel screenings 80
Physical tests of gravel screenings 86
Method 86
Granularmetric analysis 86
Granularmetric curves 86
Comparison between measured and computed voids 87
Uniformity coefficient 87
Physical tests of gravel-screenings mortars 87
Method 87
Tensile strength 88
Compressive strength 88
Summary of gravel mortar tests 88
Density 88
Stone-screenings mortars 92
Acknowledgment of donations 92
Method of collection 93
Descriptions of stone screenings 93
Physical tests of stone screenings 106
Method 106
Granularmetric analysis 106
Granularmetric curves 106
Comparison between measured and computed voids 106
Physical tests of stone-screenings mortars 107
Method 107
Tensile strength 107
Compressive strength 108
Transverse strength 108
Summary of stone-screenings mortar tests 108
Density 109
Index 125

TABLES.

	Page.
TABLE I. Chemical analyses of seven Portland cements and resulting mixtures	11
II. Physical tests of seven Portland cements and resulting mixtures:	
a, Physical properties	13
b, Tensile strengths	16
c, Compressive strengths	19
III. Gain in tensile strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days	28
IV. Gain in tensile strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days	29
V. Gain in compressive strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days	31
VI. Gain in compressive strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days	32
VII. Strengths of typical Portland cement used in mortar tests:	
a, Tensile	36
b, Compressive	37
c, Transverse	41
VIII. Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25	59
IX. Strength of the mortars of 22 sands:	
a, Tensile	62
b, Compressive	67
c, Transverse	73
X. Chemical analyses of silt contained in 17 sands, 11 gravel screenings, and 24 stone screenings	77
XI. Uniformity coefficient of 22 sands, and 12 gravel screenings	78
XII. Average physical properties of 22 sands, 12 gravel screenings, and 25 stone screenings and their mortars	78
XIII. Strength of the mortars of 12 gravel screenings:	
a, Tensile	89
b, Compressive	91
XIV. Strength of the mortars of 25 stone screenings:	
a, Tensile	109
b, Compressive	115
c, Transverse	121

ILLUSTRATIONS.

		Page.
PLATE I.	River sands, samples 1, 2, and 3	40
II.	Bank and river sands, samples 4, 5, and 6	42
III.	Bank sands, samples 7, 8, and 9	44
IV.	Sands and mixtures, samples 10, 11, and 12	46
V.	Bank and river sands, samples 13, 14, and 15	48
VI.	River and bank sands, samples 16, 17, and 18	50
VII.	Bank and river sands, samples 19, 20, and 21	52
VIII.	*A*, River sand, sample 22; *B*, Standard Ottawa sand; *C*, Bar gravel screenings, sample 1	54
IX.	Bar and bank gravel screenings, samples 2, 3, and 4	80
X.	Bank gravel screenings, samples 5, 6, and 7	82
XI.	Bank, river, and lake gravel screenings, samples 8, 9, and 10	84
XII.	Bank gravel screenings, samples 11 and 12; limestone screenings, sample 1	86
XIII.	Limestone screenings, samples 2, 3, and 4	94
XIV.	Limestone screenings and chats, samples 5, 6, and 7	96
XV.	Chats, samples 8, 9, and 10	98
XVI.	Limestone screenings, samples 11, 12, and 13	100
XVII.	Limestone screenings and chats, samples 14, 15, and 16	102
XVIII.	Granite and limestone screenings, samples 17, 18, and 19	104
XIX.	Stone screenings, samples 20, 21, and 22	106
XX.	Limestone screenings, samples 23, 24, and 25	108
FIG. 1.	Curves showing variation of tensile strength with age of neat cement	23
2.	Curves showing variation of tensile strength with age of 1:3 standard-sand mortar	24
3.	Curves showing variation of compressive strength with age of neat cement	26
4.	Curves showing variation of compressive strength with age of 1:3 standard-sand mortar	34
5.	Gain in tensile and compressive strengths of neat cement and 1:3 standard-sand mortar	34
6.	Curves showing variation of tensile strength with age of typical cement	35
7.	Curves showing variation of compressive strength with age of typical cement	39
8.	Curves showing variation of transverse strength with age of typical cement	40
9.	Granularmetric analysis curves for sands 15, 21, 17, and 10	45
10.	Granularmetric analysis curves for sand 1, 18, 14, and 7	48
11.	Granularmetric analysis curves for sands 22, 6, 2, and 5	50
12.	Granularmetric analysis curves for sands 20, 3, 9, 11, and 19	52

Page.
FIG. 13. Granularmetric analysis curves for sands 8, 12, 13, 4, and 16 ---- 54
14. Granularmetric analysis curves for gravels 4, 12, 10, and 2 ------ 81
15. Granularmetric analysis curves for gravels 5, 6, 11, and 1 -------- 83
16. Granularmetric analysis curves for gravels 3, 8, 9, and 7 -------- 85
17. Granularmetric analysis curves for stone screenings 21, 11, 19, and 3 ---------- 94
18. Granularmetric analysis curves for stone screenings 12, 16, 1, and 2 ---------- 96
19. Granularmetric analysis curves for stone screenings 13, 22, 25, and 18 ---------- 98
20. Granularmetric analysis curves for stone screenings 10, 7, 17, and 8 ---------- 100
21. Granularmetric analysis curves for stone screenings 9, 20, 14, and 23 ---------- 102
22. Granularmetric analysis curves for stone screenings 6, 4, 15, 5, and 24 ---------- 105

ABBREVIATIONS USED IN REGISTER NUMBERS.

Ct.=cement.
Cr.=cinder.
Gl.=gravel.
Sd.=sand.
Se.=stone.
Sg.=slag.

INTRODUCTION.

By Joseph A. Holmes.

The records here reported are based on 25,000 tests, extending over more than one year of active field and laboratory work. The report may be divided into two parts—the first dealing with tensile, compressive, and other tests, including chemical analyses of Portland cement of different brands donated for the purpose, and of the mortars mixed therewith in which a standard sand was used; the second dealing with tests of mortars prepared by mixing typical Portland cement with 22 sands, 12 gravel screenings, and 25 stone screenings, procured from different parts of the United States and mixed in different proportions.

In order that tests extending over a period of years might be made with a relatively uniform cement, a quantity of Portland cement of seven different brands was obtained by donation. An equal amount of each of these brands was mixed together to form a typical Portland cement, and the mixture was stored away in air-tight cans (p. 10). Tests made to determine the quality and variation of the typical Portland cement were conducted in great detail both on the neat individual brands and the typical mix, and on 1:3 cement mortars made therefrom with standard sand.

The results of the tests showing variation in tensile strength with age of neat cement indicate clearly that the typical mix reached maximum tensile strength in 90 days, or at the same period at which this strength was reached by the separate brands; that it maintained the highest tensile strength for a period as long as that of the best of the individual brands, viz, to 180 days, and that the diminution in tensile strength thereafter to one year and beyond was less than for some brands and no greater than for the best (p. 23).

The tests of the standard-sand mortars showed maximum tensile strength of the mix at 90 days, or about the same as for the individual brands; more rapid falling off in tensile strength for the mix up to 180 days than for the individual brands; but an actual gain in strength beyond 180 days for the mix, as compared with a falling off for the separate brands (p. 24).

In the compressive tests the typical mix showed a rapid rise in strength, as did the individual brands, up to 90 days, and a less rapid but continual increase in compressive strength to the 360-day period for the mix as compared with some of the brands, four of which showed little or no gain in compressive strength after 180 days (p. 26).

Compressive tests of the 1:3 standard-sand mortars showed a more rapid gain up to 180 days for the typical mix than for the separate cement brands, and continued increase in compressive strength beyond 180 days for the mix, as against a less ratio of increase for several of the individual brands tested.

The general indications of these tests are that a cement exhibiting greater uniformity of behavior is likely to be procured by making a typical mix of several brands than by the use of any one standard brand of cement.

It should be borne in mind, however, that this statement is applicable only to the typical mixes used in these tests, and that it is possible that other mixtures of Portland cements might not yield the same results, but would show entirely different characteristics. Results of further investigations along these lines will be reported as soon as they become available.

A study of the percentage of gain in strength exhibited by the various cements and cement mortars tested shows the very important fact that though the cements may test low or high at 7 days, and though there may be varying percentages of increase during the four periods from 7 days to one year, yet after the 180-day and the 360-day tests the strengths of all the standard-sand mortars were reasonably close one to another. This indicates that early strengths may vary considerably without seriously affecting the later strength of the cement or mortar (p. 33).

The purpose of the investigations of the constituent materials of mortar was to ascertain as far as possible the properties of such materials collected in different parts of the United States. It is believed that the results of these tests made on material obtained near the large commercial centers of the country will indicate clearly to users of cement and of concrete where they may most conveniently and cheaply procure the requisite sand, gravel, etc., and how these should be mixed to attain the best result in tensile or compressive strength for each group of constituent materials.

A study of the data in this part of the report should afford means of determining the probable strength of mortar made from materials having similar properties, though gathered in different parts of the country, and should aid the constructor to decide which of the three materials—sand, gravel, or broken stone screenings—will best serve his purpose.

The tests whose results are here presented were made on mortars using different proportions of the typical Portland cement and sands, gravel screenings, and stone screenings collected in various parts of the country, the properties of which are discussed in the earlier part of the bulletin. The report describes the material, the locality of its occurrence, and the methods of screening, grading, etc., employed. The relative proportion of larger or smaller particles in the materials tested is not only described in detail and diagrammatically, but is well illustrated by reproductions of photographs made to exact scale.

Considering these tests in respect to the percentage of voids, it appears that the tensile strength decreases with the increase of void spaces. The strength of the mortars is invariably much greater when made from sands having a small percentage of voids than when made from sands having a large percentage. The strength of mortars of different proportions is also greater for those sands which have a small percentage of voids. This condition is the same in regard to both tensile strength and compressive strength, and indicates that the greatest strength can be obtained by the use of mortar in which the sand is uniformly graded. The same is true of tests of transverse strength, except that the difference is not so marked as in the tensile and compressive tests (p. 57).

The tests show a greater uniformity in general when made at the end of 180 days than when made for shorter periods. The early strength appears to be easily affected by alteration in environment, and the regularity in strength for the earlier periods appears to depend on the nature of the cement.

In tests of density of mortar, it appears that the density values are greatest for the least percentage of voids, and that the weight per cubic foot and the strength are greatest under the same conditions (p. 58).

In the tests of mortars made with gravel screenings only that material which passed a ¼-inch screen was used, and this amounted as a rule to less than 40 per cent of the sample received at the laboratory. As in the description of tests of mortars made with sand, complete details are given of the diameter of the particles in inches, with numbers of sieves passed; of the place in which samples were taken; and of physical and chemical tests. In these tests there is apparently a greater lack of uniformity in the increase of strength, probably owing to physical differences in the gravel screenings. In general the tensile strength seems to increase with the decrease in percentage of voids (p. 88). This is also true of the compressive strength. There was great irregularity in the results of the tests on account of the difficulty in obtaining a thoroughly uniform mass, especially when the material was composed of coarse grains of ap-

proximately one size. In this case it invariably happened that the cement and gravel screenings occurred in many of the test pieces in streaks, the cement accumulating on one side of the neck of the test briquet, thus reducing the active section and possibly furnishing one element of weakness (p. 88).

The tests of stone screenings collected in different parts of the country were made in the same manner as those described for sand and gravel screenings. Samples were also collected as described for the other tests. The results of these tests showed that in general the mortars made from screenings that are most nearly uniform in grading have greater strength than those made from the finer screenings, farthest removed from uniform grading. Also the strength of mortars made from the samples having a lower proportion of voids is greater than that of mortars made from screenings in which the voids are greater. This appears to be true also of the compressive tests, in which the strength of the mortar is greater for samples most uniform in grade. As shown by these tests the transverse strength does not vary much after ninety days (p. 108). The tests indicate that no definite law can be given by means of which the strength of mortars made from stone screenings can be approximately foretold from the mechanical conditions, because the strength of the stone itself from which the screenings are derived has an important bearing on the strength of the resulting mortar. The same tendency was observed in the stone-screenings mortars as in the gravel-screenings mortars for the cement to concentrate at one or more parts of the test-briquet sections.

This report is the third of a series now in process of publication by the technologic branch of the Geological Survey. It is preliminary to a group of reports which describe in detail the results of tests of various structural forms made of concrete and reenforced concrete at the structural-materials testing laboratories of the Survey at St. Louis. The first volume of this series is Bulletin No. 324, a report on the effects of the San Francisco earthquake and fire on structures and structural materials. Bulletin No. 329, the second of this series, describes in detail the organization, equipment, and methods of test adopted at these laboratories. The present bulletin, as summarized above, describes the investigations leading to the adoption of a typical Portland cement for testing purposes and the tests of mortars made by mixing sand and its substitutes—gravel and broken stone screenings—with such typical cement, as an experimental study in the progress of the survey of the constituent materials of cement mortars and concrete in the United States.

A succeeding bulletin will describe tests of the solid stone from the same quarries as those from which were obtained the stone screenings on which the tests described in this volume were made. These re-

sults may afford some basis for comparison of the relative values of mortars made from the stone screenings described herein. Other reports will deal with the results of tests of the constituent materials of concrete as distinguished from those of mortars, and with the results of additional tests of the constituent materials of mortars. These papers will be followed by a preliminary report of the results of tests of plain concrete beams and of cement-mortar building blocks. The same constituent materials have also been assembled in the form of reenforced concrete beams, reenforced concrete slabs, and plain and reenforced concrete columns, many tests on which have already been completed, and the results are now in preparation for publication. Other reports in this series will include results of investigations of shear and the modulus of elasticity in tension and compression.

Parallel with this series of reports of the results of tests being made at the St. Louis laboratories there is to be published a report on the results of a series of tests made in the testing laboratories of various technological institutions. These tests were made in cooperation with the structural-materials laboratories of the United States Geological Survey and the joint committee on concrete and reenforced concrete of the engineering societies.

In the supervision of the tests herein described and in the preparation of the report Mr. Richard L. Humphrey, engineer in charge, has had the constant active assistance of Mr. William Jordan, jr., assistant engineer.

PORTLAND CEMENT MORTARS AND THEIR CONSTITUENT MATERIALS: RESULTS OF TESTS, 1905–1907.

By Richard L. Humphrey and William Jordan, Jr.

GENERAL STATEMENT.

NATURE AND EXTENT OF THE INVESTIGATIONS.

Scope of the work.—A report on the results of the series of approximately 35,000 tests made at the structural-materials testing laboratories, Forest Park, St. Louis, Mo., of a number of sands, gravel and stone screenings, gravels, and crushed stone customarily used in cement mortars and concretes will be contained in two bulletins, the present volume dealing with investigations of these materials as constituents of mortar, and a later one as constituents of concrete.

These materials were collected in many different parts of the United States and were shipped to the laboratories in double sacks in order to avoid losing any fine material. At the time the samples were collected a report was made on the nature of the supply, the location, the approximate extent of the deposit, the manner of handling, and the market supplied.

The equipment and methods used in making these tests are fully described in Bulletin No. 329. The present bulletin contains the results of approximately 25,000 tests of 22 sands, 12 gravel screenings, and 25 stone screenings in the form of mortar, using different proportions of typical Portland cement (a mixture of seven different brands).

The purpose of the investigations of the constituent materials of mortar is to ascertain as far as possible the properties of the materials collected in different parts of the country, and to establish the relation existing between the unaltered materials and the mortars in which they are used.

It is hoped that these tabulated data will afford a means for determining the probable strength of mortar made from materials having similar properties, and thus eliminate the delay in practical work

incident to testing the materials which are to be used. It will also afford a means of comparison of materials used in different parts of the country.

Register number.—Each sample of material received at the laboratories was given a register number, a record of which was made and filed in a card index. This register number, by which the sample was known, was so chosen that it indicated the nature of the material. For example, the material was represented by the first and last letters of its name, thus: "Ct." stands for cement, "Sd." for sand, "Gl." for gravel, "Cr." for cinder, "Sg." for slag, "Se." for stone. The first sample of cement was called "Ct. 1," the next "Ct. 2," etc. When a number of brands of cement were mixed, the mixture was given a number, and each sample taken from that mixture was given a subnumber; thus the second mix of cement was called "Ct. 133," and the first sample from that mix was called "Ct. 133–1," the second "Ct. 133–2," etc.

Outline of tests.—The Portland cement used in these investigations was tested for its physical properties, including its tensile and compressive strength neat for 1, 7, 28, 90, 180, and 360 days; and with three parts of standard Ottawa sand for 7, 28, 90, 180, and 360 days.

Portions of the sands, gravel screenings, and stone screenings, all of which passed a ¼-inch screen, were sifted through Nos. 10, 20, 30, 40, 50, 80, 100, and 200 sieves; they were mixed with typical Portland cement in proportions of 1:3 and 1:4, and tested for tensile, compressive, and transverse strength at 7, 28, 90, 180, and 360 days.

In addition, when there was sufficient material of approximately one size, say between Nos. 20 and 30 sieves or between Nos. 30 and 40 sieves, tests of strength for the same periods were made on what is designated in this bulletin "1:3 one-size" mortar.

TESTS OF STRENGTH.

Storage.—The test pieces were stored in a moist closet for 24 hours prior to removal from the molds, and were then immersed in running water, maintained at approximately 70° F., until tested.

Tension.—The briquets for the tests of tensile strength are of standard form, approximately 1 square inch in section.

The Fairbanks cement-testing machine, which is used in testing these briquets, has clips with rear horizontal straps for adjusting and is provided with roller bearings. Less than 1 per cent of all briquets tested at the laboratories have broken in the clips—the great majority of the test pieces breaking fairly in the center.

Compression.—The test pieces for tests of compressive strength are 2-inch cubes and are tested generally in a 40,000-pound hydraulic

hand-operated machine; the other cubes, especially of neat cement, were tested in a 200,000-pound motor-driven screw machine.

The values given in the tables of the tests of compression are in pounds per square inch, and were found by dividing the total load on a test piece by its area, taken at 4 square inches.

Transverse.—Transverse test pieces are 1 inch square in cross section and 13 inches long, and were tested on a span of 12 inches. The surfaces in contact with the vertical sides of the mold were placed in a horizontal position in the testing machine, in order to insure a uniform depth of 1 inch.

Only the breaking load applied at the center of the span was recorded. The values given in the tables are the moduli of rupture in pounds per square inch, determined from the formula $s=\frac{Mc}{I}$.

In the present case $M=3$ W (inch-pounds), $c=\frac{1}{2}$ inch and $I=\frac{1}{12}$; therefore

$$s=\frac{3\ W\times\frac{1}{2}}{1/12}=18\ W.$$

That is, the value given in the table is in every case just 18 times the breaking load.

Results of tests.—The results of tests are given in tables and shown graphically wherever possible.

TESTS OF CEMENT.

INDIVIDUAL BRANDS AND TYPICAL PORTLAND CEMENT.

Acknowledgment of donations.—The cement used in these investigations was generously donated by the following companies:

Alpha Portland Cement Company, Alpha, N. J.
Atlas Portland Cement Company, Hannibal, Mo.
Bonneville Portland Cement Company, Siegfried, Pa.
Iola Portland Cement Company, Iola, Kans.
Lehigh Portland Cement Company, Mitchell, Ind.
Sandusky Portland Cement Company, Sandusky, Ohio.
Vulcanite Portland Cement Company, Vulcanite, N. J.

Method of tests.—The seven brands of cement were first tested separately, and afterwards thoroughly intermixed and the mixtures carefully tested. This procedure was followed in order to determine the relation between the properties of the individual brands and the properties of the mixtures made from them. It was found that the difference was so slight that in subsequent investigations the different brands of cement were thoroughly mixed as soon as received, and the mixture is called "typical Portland cement."

Selection of samples.—The complete series of determinations of the physical properties of each brand necessitated a sample of 70 pounds from each barrel, and in order to get a representative sample the barrelful was spread on a concrete floor in a uniform layer over a space of about 8 square feet. This was marked off into 25 squares, and a portion from each square was taken in such amount as to give a 70-pound sample. Each of the 70-pound samples was spread over an 8-foot square and divided into 25 squares in the same manner as the larger samples, and a portion sufficient to give a 2-pound sample was taken from each of the smaller squares. This sample, which was given the sample register number, was placed in a glass jar and reserved for chemical analysis. This procedure gave a 68-pound sample for the physical test and a 2-pound sample for chemical analysis from each barrel.

Mixing of typical Portland cement.—The next step was to take 1 barrel (less the 70 pounds extracted) from each of the seven brands and thoroughly mix them together in a cubical mixer. This mixture was dumped on a concrete floor and spread in a layer of even thickness over about 8 square feet and was divided into 25 squares, from each of which sufficient cement was taken to make a 70-pound sample. The 70-pound sample from each mixture was given a register number and was used in the tests to represent the mixture from which it was taken. This operation was repeated ten times, since there were 10 barrels of each brand.

After the 70-pound sample had been taken from each mixture the balance was stored in hermetically sealed galvanized-iron cans, each of about 800 pounds capacity. In subsequent tests made with this mixed cement the 70-pound sample in each case is referred to as the "mix," while the mixture itself is called "typical Portland cement."

Chemical analyses.—The 2-pound sample taken from each barrel and from each mix of 7 barrels was very carefully analyzed for silica, alumina, ferric oxide, lime, magnesia, and sulphuric anhydride. In these analyses the methods recommended by the committee on uniformity in the technical analysis of materials for the Portland cement industry of the New York section of the Society for Chemical Industry were used, with the following exceptions: The silica was not purified with HFl and H_2SO_4; the precipitated iron and aluminum hydrates were dissolved in dilute HNO_3 instead of dilute HCl; the ignited CaO was dissolved in dilute HCl before precipitation; the magnesium was precipitated from a HNO_3 solution the second time; lastly, the SiO_2 was not determined in the ignited $(FeAl)_2O_3$.

The results of the chemical analyses are given in Table I. The seven different brands are designated A, B, C, D, E, F, and G, and at the close the 10 mixes are indicated.

TABLE I.—*Chemical analyses of seven Portland cements and resulting mixtures (results in per cent).*

Brand.	Register No.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	SO_3.	Undeter.
A	Ct. 1	22.03	7.72	3.26	62.66	2.42	1.13	0.78
	Ct. 2	22.12	7.43	3.23	62.33	2.31	1.21	1.37
	Ct. 13	22.19	7.15	3.35	62.60	2.28	1.14	1.29
	Ct. 17	21.80	7.01	3.66	62.45	2.44	1.27	1.37
	Ct. 21	21.75	7.09	3.56	62.68	2.47	1.14	1.31
	Ct. 34	21.90	6.97	3.48	62.51	2.32	1.23	1.59
	Ct. 41	21.87	6.82	3.57	62.59	2.25	1.14	1.76
	Ct. 48	22.14	7.56	3.23	62.45	2.34	1.27	1.01
	Ct. 55	21.99	7.45	3.23	62.47	2.42	1.15	1.29
	Ct. 62	22.12	7.15	3.33	62.53	2.48	1.23	1.16
	Average	21.99	7.24	3.39	62.53	2.37	1.19	1.29
B	Ct. 3	20.86	7.76	2.38	62.92	2.51	1.61	1.[illegible]
	Ct. 7	20.96	7.48	2.68	62.60	2.56	1.70	2.07
	Ct. 14	21.05	7.60	2.53	62.64	2.33	1.60	2.25
	Ct. 22	20.56	7.67	2.48	62.53	3.08	1.75	1.93
	Ct. 23	21.04	7.48	2.63	62.66	2.49	1.57	2.13
	Ct. 35	20.54	7.96	2.72	62.79	2.35	1.61	2.03
	Ct. 42	20.34	8.07	2.57	63.05	2.41	1.74	1.82
	Ct. 49	20.21	7.19	2.67	62.77	2.62	1.71	2.83
	Ct. 56	21.11	7.95	2.67	62.77	2.85	1.60	1.05
	Ct. 63	20.86	8.02	2.68	62.75	2.88	1.66	1.15
	Average	20.75	7.72	2.59	62.75	2.61	1.66	1.92
C	Ct. 4	20.83	8.38	2.49	63.23	3.20	1.35	.52
	Ct. 8	21.08	7.75	2.73	62.92	3.13	1.48	.91
	Ct. 15	21.04	8.08	2.58	63.32	3.19	1.42	.37
	Ct. 24	20.84	7.89	2.78	62.92	2.82	1.44	1.31
	Ct. 27	21.31	7.70	3.07	63.20	2.54	1.50	.68
	Ct. 36	20.60	8.27	2.58	63.03	2.86	1.55	1.11
	Ct. 43	21.01	7.75	2.57	63.03	2.67	1.47	1.50
	Ct. 50	20.95	7.98	2.53	62.51	2.78	1.40	1.85
	Ct. 57	20.52	7.63	3.07	62.89	2.69	1.49	1.71
	Ct. 64	20.66	7.68	2.57	62.79	2.62	1.48	2.20
	Average	20.88	7.91	2.69	62.98	2.85	1.46	1.22
D	Ct. 5	21.56	8.48	3.11	62.41	2.21	1.53	.70
	Ct. 9	21.50	8.27	3.23	62.43	2.21	1.60	.76
	Ct. 16	21.65	8.34	2.97	62.46	2.64	1.55	.39
	Ct. 25	21.38	8.42	2.87	62.58	2.27	1.39	1.09
	Ct. 30	21.93	7.46	3.23	62.64	2.46	1.53	.75
	Ct. 37	21.57	8.01	3.37	62.62	2.17	1.47	.79
	Ct. 44	21.93	7.46	3.23	62.64	2.40	1.53	.81
	Ct. 51	21.33	7.55	3.16	62.49	2.45	1.57	1.45
	Ct. 58	21.56	7.32	3.26	62.65	2.43	1.51	1.27
	Ct. 65	21.68	7.48	3.42	62.69	2.46	1.54	.73
	Average	21.61	7.88	3.18	62.56	2.37	1.52	.87
E	Ct. 6	23.33	5.26	3.37	63.01	2.96	1.14	0.93
	Ct. 10	23.30	5.61	2.83	63.10	2.90	1.11	1.15
	Ct. 18	23.48	5.29	3.22	63.19	3.03	1.41	.38
	Ct. 26	23.34	5.46	3.17	63.05	3.10	1.33	.55
	Ct. 31	23.40	5.03	3.42	63.31	2.92	1.42	.50
	Ct. 38	22.86	5.40	3.42	63.44	3.20	1.35	.33
	Ct. 45	22.77	5.53	3.27	63.24	2.79	1.40	1.00
	Ct. 52	23.10	5.37	3.27	63.28	3.05	1.32	.61
	Ct. 59	23.30	5.24	3.37	63.01	3.05	1.42	.61
	Ct. 66	23.62	5.05	3.37	62.74	3.14	1.26	.82
	Average	23.25	5.32	3.27	63.14	3.01	1.32	.69
F	Ct. 11	22.32	7.29	2.98	62.38	1.62	1.66	1.75
	Ct. 19	22.21	7.24	2.92	62.30	1.28	1.49	2.56
	Ct. 28	22.14	7.14	3.01	62.21	1.38	1.66	2.46
	Ct. 32	21.90	7.19	2.97	62.41	1.36	1.37	2.80
	Ct. 39	22.18	7.48	3.09	62.35	1.72	1.57	1.61
	Ct. 46	22.34	7.41	3.04	62.45	1.75	1.64	1.37
	Ct. 53	21.94	7.90	3.08	62.43	1.74	1.65	1.26
	Ct. 60	22.04	7.18	3.04	62.36	1.78	1.61	1.99
	Ct. 67	22.15	7.08	3.04	62.37	1.82	1.55	1.99
	Average	22.14	7.32	3.02	62.36	1.61	1.58	1.98
G	Ct. 12	22.50	6.65	2.89	60.04	3.20	1.95	2.77
	Ct. 20	23.04	6.70	2.66	60.18	3.25	1.83	2.34
	Ct. 29	22.78	6.80	2.58	59.96	3.29	1.80	2.79
	Ct. 33	22.84	6.97	2.51	59.96	3.35	1.90	2.47
	Ct. 40	22.30	7.25	2.84	60.98	3.20	1.40	2.03
	Ct. 47	21.92	7.21	2.88	60.88	3.21	1.47	2.43
	Ct. 54	22.92	6.78	3.04	60.18	3.28	1.70	2.10
	Ct. 61	22.26	7.12	2.84	60.82	3.09	1.52	2.35
	Ct. 68	21.90	7.03	2.88	60.80	3.14	1.54	2.71
	Average	22.47	6.94	2.79	60.42	3.23	1.67	2.44
	Average A–G	21.86	7.19	2.99	62.42	2.58	1.48	1.47
Mix. 1	Ct. 69	22.28	6.92	3.11	62.89	2.81	1.40	.59
2	Ct. 70	22.16	6.65	3.07	62.44	2.77	1.43	1.48
3	Ct. 71	21.81	6.81	3.27	62,79	2.62	1.38	1.32
4	Ct. 72	22.34	6.92	3.22	62.60	2.71	1.47	.74
5	Ct. 73	22.10	6.94	3.12	62.80	2.66	1.47	.91
6	Ct. 74	22.18	6.71	3.17	62.70	2.55	1.41	1.28
7	Ct. 75	21.80	6.66	3.27	62.67	2.62	1.42	1.56
8	Ct. 76	21.79	6.77	3.32	62.90	2.45	1.40	1.37
9	Ct. 77	21.61	6.69	3.31	62.67	2.52	1.60	1.60
10	Ct. 78	21.98	6.75	3.22	62.89	2.69	1.65	.82
	Average	22.01	6.78	3.21	62.74	2.64	1.46	1.17

The register number given each sample is the same as that used in later tables giving the results of the physical tests, so that the chemical analysis of any particular sample can be compared with the physical properties of the cement from which the sample for chemical analysis was taken. But 9 samples of each of brands F and G were used, making a total of 68 samples of the individual brands and 10 samples of typical Portland cement analyzed and recorded in the table.

The average values for each brand are given at the bottom of its group, and the average value for the seven brands is given near the end of the table. For purposes of comparison, the average values for the 10 samples of typical Portland cement are also given in the last line. The small difference between the averages of the 68 samples, designated "Average A–G," and the averages of the 10 samples of typical Portland cement indicates that the typical Portland cements are representative of the individual brands.

PHYSICAL DETERMINATIONS.

Method.—A portion of the 68-pound sample taken from each of 68 barrels and from each of the 10 mixtures was subjected to the usual physical tests, consisting of determinations of specific gravity, temperatures of water and air, per cent of water for normal consistency, time of initial and final setting, fineness, constancy of volume (soundness), and the tensile and compressive strengths. The physical determinations were made at about the time of mixing the cements and before they were stored, and are given in Table II.

G	Ct. 12	3.100	75.8	81.0	21.0	106	233	190	275	4.0	23.1	Do.
	Ct. 20	3.100	77.1	80.2	21.0	174	354	219	359	6.4	21.2	Do.
	Ct. 29	3.100	76.3	78.1	20.5	95	346	225	388	4.9	23.0	Do.
	Ct. 33	3.115	79.3	82.6	21.0	73	313	223	388	4.8	24.5	Do.
	Ct. 40	3.100	73.4	69.8	21.0	152	363	215	403	4.4	24.8	Do.
	Ct. 47	3.105	71.6	71.8	20.5	205	400	265	430	4.6	24.0	Do.
	Ct. 54	3.100	73.2	74.8	20.5	145	340	200	442	4.5	23.1	Do.
	Ct. 61	3.106	69.8	71.8	20.5	142	370	242	452	4.9	23.3	Do.
	Ct. 68	3.100	70.0	66.9	20.5	185	397	216	453	4.9	24.1	Do.
	Average	3.103	74.1	75.2	20.7	142	346	222	399	4.8	23.4	
	Average A–G	3.120	74.5	75.7	21.4	156	339	228	376	5.9	22.3	
Mix. 1	Ct. 69	3.115	66.9	70.0	21.5	167	379	198	378	7.0	24.9	Do.
2	Ct. 70	3.120	66.9	70.0	22.5	235	422	250	430	7.3	24.7	Do.
3	Ct. 71	3.106	68.0	70.0	21.0	210	380	280	465	6.7	24.3	Do.
4	Ct. 72	3.120	68.0	70.0	21.0	195	385	260	445	6.7	24.7	Do.
5	Ct. 73	3.126	68.0	70.0	21.0	157	337	237	427	6.1	24.7	Do.
6	Ct. 74	3.119	71.2	72.3	21.5	209	368	253	430	6.9	24.7	Do.
7	Ct. 75	3.125	71.2	72.3	21.5	237	387	287	457	6.5	24.3	Do.
8	Ct. 76	3.127	71.2	72.3	21.5	220	395	270	445	7.1	24.5	Do.
9	Ct. 77	3.149	72.3	74.1	21.5	185	370	215	415	6.2	22.4	Do.
10	Ct. 78	3.116	72.3	74.1	21.5	182	402	227	449	5.2	23.8	Do.
	Average	3.122	69.6	71.5	21.5	200	383	248	434	6.6	24.3	

TABLE IIa.—*General physical properties of seven Portland cements and resulting mixtures*—Continued.

Brand.	Register No.	Specific gravity.	Temperature (° F.).		Water (per cent).	Time of set (minutes).				Fineness—per cent residue on sieve No.—		Soundness.
			Water.	Air.		By Vicat apparatus.		By Gilmore apparatus.				
						Initial.	Final.	Initial.	Final.	100	200	
1	2	3	4	5	6	7	8	9	10	11	12	13
D	Ct. 5	3.150	76.2	77.4	21.0	146	276	184	277	7.4	24.6	Pat A warped 1/16 inch.
	Ct. 9	3.119	76.3	80.0	21.0	124	324	242	379	7.4	24.8	Do.
	Ct. 16	3.140	76.7	83.2	21.0	95	320	225	365	7.8	24.6	Perfectly sound.
	Ct. 25	3.107	77.1	81.2	21.0	214	305	229	374	7.7	23.8	Do.
	Ct. 30	3.145	78.8	81.0	21.0	107	336	242	342	7.5	25.0	Do.
	Ct. 37	3.117	73.4	71.6	21.0	185	325	215	380	7.4	24.7	Do.
	Ct. 44	3.118	73.6	71.6	21.0	132	377	292	397	7.3	24.1	Do.
	Ct. 51	3.132	71.6	72.1	21.0	270	445	315	492	7.6	24.6	Do.
	Ct. 58	3.121	70.2	69.8	21.0	203	386	247	450	7.8	24.9	Do.
	Ct. 65	3.117	70.2	69.4	21.0	210	473	248	470	7.7	23.6	Do.
	Average	3.127	74.4	75.7	21.0	169	357	244	393	7.6	24.5	
E	Ct. 6	1.195	76.1	78.0	20.5	182	362	290	422	7.5	24.1	Do.
	Ct. 10	3.111	76.6	79.0	20.5	148	293	168	298	7.7	24.9	Pat A warped 1/16 inch.
	Ct. 18	3.154	76.2	79.1	21.0	193	388	275	455	7.2	24.0	Perfectly sound.
	Ct. 26	3.121	77.1	79.1	21.0	201	370	258	421	7.5	25.0	Do.
	Ct. 31	3.112	78.8	85.8	21.0	190	415	203	411	7.0	24.4	Do.
	Ct. 38	3.148	73.4	71.6	21.0	198	348	243	388	6.4	23.8	Do.
	Ct. 45	3.148	71.6	71.6	21.5	240	380	340	440	7.1	25.0	Do.
	Ct. 52	3.143	71.6	72.1	21.5	270	480	270	490	7.2	24.2	Do.
	Ct. 59	3.181	72.0	69.8	21.5	293	480	293	493	7.0	24.3	Do.
	Ct. 66	3.169	70.2	69.4	21.5	217	457	265	443	7.4	24.3	Do.
	Average	3.148	74.4	75.6	21.1	213	397	261	426	7.2	24.4	
F	Ct. 11	3.108	76.2	80.1	21.5	118	318	193	320	6.6	22.0	Pat A warped 1/16 inch.
	Ct. 19	3.102	75.4	78.2	21.5	131	269	194	314	7.8	21.6	Perfectly sound.
	Ct. 28	3.110	76.3	77.4	21.5	102	415	224	386	6.4	21.2	Pat A warped 1/16 inch.
	Ct. 32	3.105	78.8	85.8	21.5	107	272	159	330	6.0	20.0	Perfectly sound.
	Ct. 39	3.100	73.4	69.8	21.5	127	302	232	389	6.0	20.0	Pat A warped 1/16 inch.
	Ct. 46	3.105	71.6	71.6	21.5	160	354	229	404	6.3	20.7	Perfectly sound.
	Ct. 53	3.108	73.2	74.8	21.5	162	347	212	452	6.0	21.1	Pat A warped 1/16-inch.
	Ct. 60	3.103	72.0	69.8	21.5	253	328	225	383	6.0	20.2	Perfectly sound.
	Ct. 67	3.100	70.2	69.4	21.5	138	399	220	399	6.0	20.7	Do.
	Average	3.104	74.1	75.2	21.5	144	334	210	375	6.3	20.7	

G	Ct. 12	3.100	75.8	81.0	21.0	106	233	190	275	4.0	23.1	Do.
	Ct. 20	3.100	77.1	80.2	21.0	174	354	210	359	6.4	21.2	Do.
	Ct. 29	3.100	76.3	78.1	20.5	95	346	225	388	4.9	23.0	Do.
	Ct. 33	3.115	79.3	82.6	21.0	73	313	223	388	4.8	24.5	Do.
	Ct. 40	3.100	73.4	69.8	21.0	152	363	215	403	4.4	24.8	Do.
	Ct. 47	3.105	71.6	71.8	20.5	205	400	265	430	4.6	24.0	Do.
	Ct. 54	3.100	73.2	74.8	20.5	145	340	200	442	4.5	23.1	Do.
	Ct. 61	3.106	69.8	71.8	20.5	142	370	242	452	4.9	23.3	Do.
	Ct. 68	3.100	70.0	66.9	20.5	185	397	216	453	4.9	24.1	Do.
	Average	3.103	74.1	75.2	20.7	142	346	222	399	4.8	23.4	
	Average A–G	3.120	74.5	75.7	21.4	156	339	228	376	5.9	22.3	
Mix. 1	Ct. 69	3.115	66.9	70.0	21.5	167	379	198	378	7.0	24.9	Do.
2	Ct. 70	3.120	66.9	70.0	22.5	235	422	250	430	7.3	24.7	Do.
3	Ct. 71	3.106	68.0	70.0	21.0	210	380	280	465	6.7	24.3	Do.
4	Ct. 72	3.120	68.0	70.0	21.0	195	385	260	445	6.7	24.7	Do.
5	Ct. 73	3.126	68.0	70.0	21.0	157	337	237	427	6.1	24.7	Do.
6	Ct. 74	3.119	71.2	72.3	21.5	209	368	253	430	6.9	24.7	Do.
7	Ct. 75	3.125	71.2	72.3	21.5	237	387	287	457	6.5	24.3	Do.
8	Ct. 76	3.127	71.2	72.3	21.5	220	395	270	445	7.1	24.5	Do.
9	Ct. 77	3.149	72.3	74.1	21.5	185	370	215	415	6.2	22.4	Do.
10	Ct. 78	3.116	72.3	74.1	21.5	182	402	227	449	5.2	23.8	Do.
	Average	3.122	69.6	71.5	21.5	200	383	248	434	6.6	24.3	

TABLE IIa.—*General physical properties of seven Portland cements and resulting mixtures*—Continued.

Brand.	Register No.	Specific gravity.	Temperature (° F.).		Water (per cent).	Time of set (minutes).				Fineness—per cent residue on sieve No.—		Soundness.
			Water.	Air.		By Vicat apparatus.		By Gilmore apparatus.				
						Initial.	Final.	Initial.	Final.	100	200	
1	2	3	4	5	6	7	8	9	10	11	12	13
D	Ct. 5	3.150	76.2	77.4	21.0	146	276	184	277	7.4	24.6	Pat A warped 1/16 inch.
	Ct. 9	3.119	76.3	80.0	21.0	124	324	242	379	7.4	24.8	Do.
	Ct. 16	3.140	76.7	83.2	21.0	95	320	225	365	7.8	24.6	Perfectly sound.
	Ct. 25	3.107	77.1	81.2	21.0	214	305	229	374	7.7	23.8	Do.
	Ct. 30	3.145	78.8	81.0	21.0	107	336	242	342	7.5	25.0	Do.
	Ct. 37	3.117	73.4	71.6	21.0	185	325	215	380	7.4	24.7	Do.
	Ct. 44	3.118	73.6	71.6	21.0	132	377	292	397	7.3	24.1	Do.
	Ct. 51	3.132	71.6	72.1	21.0	270	445	315	492	7.6	24.6	Do.
	Ct. 58	3.121	70.2	69.8	21.0	203	386	247	450	7.8	24.9	Do.
	Ct. 65	3.117	70.2	69.4	21.0	210	473	248	470	7.7	23.6	Do.
	Average	3.127	74.4	75.7	21.0	169	357	244	393	7.6	24.5	
E	Ct. 6	1.195	76.1	78.0	20.5	182	362	290	422	7.5	24.1	Do.
	Ct. 10	3.111	76.6	79.0	20.5	148	293	168	298	7.7	24.9	Pat A warped 1/16 inch.
	Ct. 18	3.154	76.2	79.1	21.0	193	388	275	455	7.2	24.0	Perfectly sound.
	Ct. 26	3.121	77.1	79.1	21.0	201	370	258	421	7.5	25.0	Do.
	Ct. 31	3.112	78.8	85.8	21.0	190	415	203	411	7.0	24.4	Do.
	Ct. 38	3.148	73.4	71.6	21.0	198	348	243	388	6.4	23.8	Do.
	Ct. 45	3.148	71.6	71.6	21.5	240	380	340	440	7.1	25.0	Do.
	Ct. 52	3.143	71.6	72.1	21.5	270	480	270	490	7.2	24.2	Do.
	Ct. 59	3.181	72.0	69.8	21.5	293	480	293	493	7.0	24.3	Do.
	Ct. 66	3.169	70.2	69.4	21.5	217	457	265	443	7.4	24.3	Do.
	Average	3.148	74.4	75.6	21.1	218	397	261	426	7.2	24.4	
F	Ct. 11	3.108	76.2	80.1	21.5	118	318	193	320	6.6	22.0	Pat A warped 1/16 inch.
	Ct. 19	3.102	75.4	78.2	21.5	131	269	194	314	7.8	21.6	Perfectly sound.
	Ct. 28	3.110	76.3	77.4	21.5	102	415	224	386	6.4	21.2	Pat A warped 1/16 inch.
	Ct. 32	3.105	78.8	85.8	21.5	107	272	159	330	6.0	20.0	Perfectly sound.
	Ct. 39	3.100	73.4	69.8	21.5	127	302	232	389	6.0	20.0	Pat A warped 1/16 inch.
	Ct. 46	3.105	71.6	71.6	21.5	160	354	229	404	6.3	20.7	Perfectly sound.
	Ct. 53	3.108	73.2	74.8	21.5	162	347	212	452	6.0	21.1	Pat A warped 1/16 inch.
	Ct. 60	3.103	72.0	69.8	21.5	253	328	225	383	6.0	20.2	Perfectly sound.
	Ct. 67	3.100	70.2	69.4	21.5	138	399	220	399	6.0	20.7	Do.
	Average	3.104	74.1	75.2	21.5	144	334	210	375	6.3	20.7	

G	Ct. 12	3.100	75.8	81.0	21.0	106	233	190	275	4.0	23.1	Do.
	Ct. 20	3.100	77.1	80.2	21.0	174	354	210	359	6.4	21.2	Do.
	Ct. 29	3.100	76.3	78.1	20.5	95	346	225	388	4.9	23.0	Do.
	Ct. 33	3.115	79.3	82.6	21.0	73	313	223	388	4.8	24.5	Do.
	Ct. 40	3.100	73.4	69.8	21.0	152	363	215	403	4.4	24.8	Do.
	Ct. 47	3.105	71.6	71.8	20.5	205	400	265	430	4.6	24.0	Do.
	Ct. 54	3.100	73.2	74.8	20.5	145	340	200	442	4.5	23.1	Do.
	Ct. 61	3.106	69.8	71.8	20.5	142	370	242	452	4.9	23.3	Do.
	Ct. 68	3.100	70.0	66.9	20.5	185	397	216	453	4.9	24.1	Do.
	Average	3.103	74.1	75.2	20.7	142	346	222	399	4.8	23.4	
	Average A–G	3.120	74.5	75.7	21.4	156	339	228	376	5.9	22.3	
Mix. 1	Ct. 69	3.115	66.9	70.0	21.5	167	379	198	378	7.0	24.9	Do.
2	Ct. 70	3.120	66.9	70.0	22.5	235	422	250	430	7.3	24.7	Do.
3	Ct. 71	3.106	68.0	70.0	21.0	210	380	280	465	6.7	24.3	Do.
4	Ct. 72	3.120	68.0	70.0	21.0	195	385	260	445	6.7	24.7	Do.
5	Ct. 73	3.126	68.0	70.0	21.0	157	337	237	427	6.1	24.7	Do.
6	Ct. 74	3.119	71.2	72.3	21.5	209	368	253	430	6.9	24.7	Do.
7	Ct. 75	3.125	71.2	72.3	21.5	237	387	287	457	6.5	24.3	Do.
8	Ct. 76	3.127	71.2	72.3	21.5	220	395	270	445	7.1	24.5	Do.
9	Ct. 77	3.149	72.3	74.1	21.5	185	370	215	415	6.2	22.4	Do.
10	Ct. 78	3.116	72.3	74.1	21.5	182	402	227	449	5.2	23.8	Do.
	Average	3.122	69.6	71.5	21.5	200	383	248	434	6.6	24.3	

TABLE IIb.—*Tensile strengths of seven Portland cements and resulting mixtures, neat and in standard mortar.*

Brand.	Register No.	Temperature (° F.).		Neat.							1:3 standard-sand mortar.					
				Water (per cent).	Tensile strength (pounds per square inch).						Water (per cent).	Tensile strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days	360 days		7 days.	28 days.	90 days.	180 days	360 days
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
A	Ct. 1	76.2	79.0	20.5	334	726	769	988	947	806	9.4	290	342	498	429	462
	Ct. 2	76.1	78.0	20.3	349	783	926	1,103	1,079	786	8.9	268	329	480	505	367
	Ct. 13	76.1	79.2	20.5	289	713	860	1,012	925	645	8.9	254	332	492	482	397
	Ct. 17	77.7	80.4	21.0	352	676	844	909	857	741	9.0	256	350	497	468	366
	Ct. 21	76.2	80.1	21.0	322	714	862	989	987	687	9.0	244	410	468	577	410
	Ct. 34	79.3	82.6	21.0	256	534	831	994	896	645	9.0	196	266	433	429	320
	Ct. 41	73.4	70.3	21.0	158	581	849	977	989	770	9.0	169	350	484	440	336
	Ct. 48	71.6	71.8	21.0	288	646	884	940	965	664	9.0	271	401	550	502	360
	Ct. 55	73.6	77.4	21.5	281	599	810	943	914	673	9.1	241	391	475	501	351
	Ct. 62	69.8	71.8	21.5	233	637	766	981	955	752	9.1	233	327	515	505	318
	Average	75.0	77.1	20.9	286	661	840	984	946	717	9.0	242	350	489	484	369
B	Ct. 3	76.4	80.0	22.5	530	820	725	955	955	669	9.3	310	323	510	522	388
	Ct. 7	75.8	77.1	22.5	588	872	787	840	834	618	9.3	297	334	493	485	357
	Ct. 14	76.4	82.3	22.0	569	821	833	861	1,042	659	9.2	308	349	510	486	416
	Ct. 22	77.7	80.4	22.5	629	766	727	863	638	651	9.3	280	355	517	310	376
	Ct. 23	76.9	79.2	22.5	464	718	801	961	852	569	9.3	277	348	458	497	410
	Ct. 35	73.6	66.1	22.5	360	762	786	903	893	604	9.3	323	386	529	485	415
	Ct. 42	73.4	70.3	22.5	316	764	673	907	857	726	9.3	306	404	568	520	348
	Ct. 49	71.8	70.4	22.5	390	616	767	865	873	637	9.3	317	409	555	506	355
	Ct. 56	73.6	77.4	22.5	418	724	759	880	898	618	9.3	319	370	508	507	382
	Ct. 63	71.6	73.8	22.5	424	656	902	908	942	704	9.3	292	476	473	505	331
	Average	74.7	75.7	22.5	469	752	776	894	878	646	9.3	303	375	512	482	378
C	Ct. 4	75.9	77.0	22.0	437	760	785	942	962	687	9.2	356	360	497	510	358
	Ct. 8	76.4	78.0	22.0	380	754	748	916	905	646	9.2	302	351	491	456	352
	Ct. 15	76.0	82.3	22.0	437	715	760	931	987	822	9.2	349	372	509	512	359
	Ct. 24	77.2	80.4	22.0	428	664	669	970	944	670	9.2	324	393	492	511	379
	Ct. 27	78.8	81.0	22.0	401	699	803	958	962	603	9.2	272	371	525	498	343
	Ct. 36	73.6	66.1	22.0	332	725	818	940	972	644	9.2	303	392	536	518	351
	Ct. 43	73.6	71.6	22.0	307	662	835	1,004	938	748	9.2	309	392	517	506	374
	Ct. 50	71.8	70.4	22.0	326	587	809	931	944	583	9.2	307	397	525	527	358
	Ct. 57	70.2	69.8	22.0	327	684	851	949	916	644	9.2	298	414	536	522	324
	Ct. 64	71.6	73.8	22.0	305	656	975	929	850	698	9.2	276	458	511	488	322
	Average	74.5	75.0	22.0	368	691	805	947	938	675	9.2	310	390	514	505	352

D	Ct. 5	76.2	77.4	21.0	396	734	786	977	1,035	716	9.0	322	345	541	545	360
	Ct. 9	76.3	80.0	21.0	377	709	753	750	911	694	9.0	301	368	511	511	369
	Ct. 16	76.7	83.2	21.0	394	701	604	984	967	648	9.0	276	372	502	519	385
	Ct. 25	77.1	81.2	21.0	255	703	863	984	937	692	9.0	315	403	504	488	398
	Ct. 30	78.8	81.0	21.0	364	671	716	984	986	623	9.0	242	379	525	557	344
	Ct. 37	73.4	71.6	21.0	258	586	810	927	973	773	9.0	262	383	515	520	327
	Ct. 44	73.6	71.6	21.0	278	649	787	958	962	710	9.0	304	341	527	501	391
	Ct. 51	71.6	72.1	21.0	319	616	843	981	1,005	690	9.0	277	387	507	532	327
	Ct. 58	70.2	69.8	21.0	322	674	804	1,017	973	817	9.0	284	400	543	514	371
	Ct. 65	70.2	69.4	21.0	253	658	960	907	972	749	9.3	215	474	513	443	500
	Average	74.4	75.7	21.0	322	670	793	947	972	711	9.0	280	385	519	513	377
E	Ct. 6	76.1	78.0	20.5	429	739	815	1,009	1,017	756	8.9	243	334	506	527	361
	Ct. 10	76.6	79.0	20.5	318	680	808	968	1,019	797	8.9	235	376	504	439	349
	Ct. 28	76.2	79.1	21.0	376	645	936	1,050	1,055	689	9.0	276	374	506	508	408
	Ct. 26	77.1	79.9	21.0	343	707	914	985	984	712	9.0	253	348	528	480	352
	Ct. 31	78.8	85.8	21.0	424	581	741	978	944	733	9.0	232	363	478	515	346
	Ct. 38	73.4	71.6	21.0	314	590	907	1,033	1,071	815	9.0	205	367	496	520	359
	Ct. 45	71.6	71.6	21.5	281	574	857	1,037	985	820	9.1	204	313	510	488	343
	Ct. 52	71.6	72.1	21.5	313	593	839	950	1,042	864	9.1	211	323	508	533	334
	Ct. 59	72.0	69.8	21.5	250	550	823	1,010	1,052	888	9.1	181	305	485	465	341
	Ct. 66	70.2	69.4	21.5	272	557	960	1,042	970	770	.....	.....	.....	.....	.....	.....
	Average	74.4	75.6	21.1	338	622	860	1,016	1,021	784	9.0	227	345	502	497	355
F	Ct. 11	76.3	80.1	21.5	404	676	751	926	873	659	9.1	341	364	516	478	396
	Ct. 19	75.4	78.2	21.5	411	628	828	937	909	577	9.1	313	435	465	477	391
	Ct. 28	76.3	77.4	21.5	396	764	857	943	823	602	9.1	310	396	457	466	359
	Ct. 32	76.8	86.8	21.5	441	736	717	735	821	616	9.1	315	389	507	495	339
	Ct. 39	73.4	69.8	21.5	318	660	772	951	928	707	9.1	323	411	500	518	332
	Ct. 46	71.6	71.6	21.5	391	572	775	967	893	653	9.1	249	415	503	491	354
	Ct. 53	73.2	74.8	21.5	323	738	865	951	962	627	9.1	285	430	490	497	326
	Ct. 60	72.0	69.8	21.5	402	689	785	965	828	541	9.1	300	408	495	497	356
	Ct. 67	70.2	69.4	21.5	354	756	932	983	878	578	9.4	192	433	499	419	407
	Average	74.1	75.3	21.5	382	691	809	929	879	618	9.1	292	409	492	482	362
G	Ct. 12	79.8	81.0	21.0	426	623	728	936	975	744	9.0	251	307	509	394	379
	Ct. 20	77.1	80.2	21.0	473	566	721	929	928	642	9.0	251	311	523	525	379
	Ct. 29	76.3	78.1	20.5	447	663	810	916	846	653	8.9	257	323	498	515	365
	Ct. 33	79.3	82.6	21.0	455	553	765	807	916	658	9.0	199	354	538	515	381
	Ct. 40	73.4	69.8	21.0	324	561	807	877	961	709	9.0	209	321	487	471	327
	Ct. 47	71.6	71.8	20.5	400	636	736	930	955	774	8.9	222	365	490	499	381
	Ct. 54	73.2	74.8	20.5	376	589	715	905	865	724	8.9	247	355	525	534	369
	Ct. 61	69.8	71.8	20.5	381	543	766	936	878	810	8.9	193	328	416	480	349
	Ct. 68	70.0	66.9	20.5	319	606	876	922	907	744	.....	.....	.....	.....	.....	.....
	Average	74.1	75.2	20.7	400	593	769	906	915	718	9.0	229	333	504	492	366
	Average A–G	74.5	75.7	21.4	262	669	808	945	937	696	9.1	270	370	505	494	366

TABLE IIb.—*Tensile strengths of seven Portland cements and resulting mixtures, neat and in standard mortar*—Continued.

Brand.	Register No.	Temperature (°F.).		Neat.							1:3 standard-sand mortar.					
				Water (per cent).	Tensile strength (pounds per square inch).						Water (per cent).	Tensile strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days	90 days.	180 days	360 days		7 days.	28 days.	90 days.	180 days	360 days
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mix. 1	Ct. 69	66.9	70.0	21.5	300	685	872	962	952	776	9.4	248	491	527	455	466
2	Ct. 70	66.9	70.0	22.5	305	686	781	893	933	769	9.4	192	420	539	424	491
3	Ct. 71	68.0	70.0	21.0	366	708	870	954	966	712	9.3	208	472	481	418	473
4	Ct. 72	68.0	70.0	21.0	356	662	824	917	968	658	.....	.....	.....	.....	.....	.....
5	Ct. 73	68.0	70.0	21.0	334	771	878	921	929	663	.....	.....	.....	.....	.....	.....
6	Ct. 74	71.2	72.3	21.5	343	683	864	934	923	657	9.1	206	415	439	423	437
7	Ct. 75	71.2	72.3	21.5	346	644	846	998	988	718	9.4	206	448	464	450	466
8	Ct. 76	71.2	72.3	21.5	370	580	857	922	948	770	9.4	212	463	557	413	430
9	Ct. 77	72.3	74.1	21.5	363	682	850	962	999	752	9.4	217	463	560	446	439
10	Ct. 78	72.3	74.1	21.5	292	669	873	924	888	752	.....	.....	.....	.....	.....	.....
	Average	69.6	71.5	21.5	337	677	852	939	949	723	9.4	213	453	510	433	457

TABLE 11c.—*Compressive strengths of seven Portland cements and resulting mixtures, neat and in standard mortar.*

Brand.	Register No.	Neat.									1:3 standard-sand mortar.							
		Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).						Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.	Water.	Air.		1 day.	28 days.	90 days.	180 days.	360 days.
1	2	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
A	Ct. 1	79.2	79.0	20.5	.....	6,371	8,531	13,237	15,292	11,631	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 2	77.7	80.4	20.3	1,262	6,084	9,427	12,319	13,367	12,616	78.8	81.0	8.9	985	1,776	2,439	2,617	2,367
	Ct. 13	73.2	74.8	20.5	983	4,957	8,308	8,653	12,176	12,534	73.6	77.4	8.9	1,022	1,633	3,213	3,611	3,125
	Ct. 17	70.9	72.3	21.0	1,739	6,402	9,724	11,334	12,653	12,756	70.5	59.0	9.0	1,287	1,521	2,603	2,375	4,012
	Ct. 21	70.7	70.0	21.0	1,395	6,961	8,877	9,369	10,888	11,537	68.0	70.0	9.0	1,328	1,554	2,918	3,009	3,562
	Ct. 34	65.8	64.1	21.0	424	3,283	5,875	9,291	10,161	11,358	70.7	61.7	9.0	594	1,554	2,344	2,609	3,987
	Ct. 41	66.0	73.0	21.0	418	3,917	8,090	9,445	10,208	8,346	70.7	68.0	9.0	1,184	1,298	2,870	3,045	3,208
	Ct. 48	69.8	68.3	21.0	304	3,221	5,463	10,475	10,829	12,559	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 55	70.5	64.6	21.5	298	2,138	6,114	9,194	9,500	11,318	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 62	69.8	68.0	21.5	305	3,009	5,558	9,390	11,346	10,495	.....	.....	.....	.....	.....	.....	.....	.....
	Average	71.1	71.5	20.9	792	4,634	7,597	10,271	11,642	11,515	72.1	69.5	9.0	1,067	1,556	2,731	2,878	3,377
B	Ct. 7	78.8	85.8	22.5	2,063	5,994	6,311	9,747	10,116	11,093	79.3	82.6	9.3	1,048	1,751	2,228	2,435	3,367
	Ct. 14	70.2	69.8	22.0	1,570	5,996	8,559	8,497	8,927	9,338	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 22	70.9	69.4	22.5	2,203	5,545	7,191	9,055	10,360	10,896	70.5	59.0	9.3	1,152	2,369	3,174	2,794	4,750
	Ct. 23	71.2	72.3	22.5	2,166	6,209	6,468	9,504	9,511	10,073	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 35	66.2	66.5	22.5	1,122	5,717	9,426	10,301	11,421	11,384	70.7	61.4	9.3	1,131	1,459	3,093	3,725	4,067
	Ct. 42	65.0	66.7	22.5	905	4,563	8,656	11,531	11,150	11,449	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 49	69.8	68.0	22.5	1,208	3,799	7,997	10,168	10,942	11,390	70.7	69.8	9.4	1,103	1,245	2,497	3,417	2,642
	Ct. 56	70.5	64.6	22.5	1,229	4,946	8,470	8,979	10,662	13,774	69.8	68.0	9.6	982	2,850	3,542	3,267	4,675
	Ct. 63	69.8	68.0	22.5	858	3,951	6,224	9,942	10,949	11,268	69.8	69.8	9.6	1,069	2,596	3,651	3,667	4,308
	Average	70.3	70.1	22.4	1,480	5,191	7,700	9,747	10,449	11,185	71.8	68.4	9.4	1,081	2,045	3,041	3,167	3,968
C	Ct. 4	76.2	80.1	22.0	.....	8,503	10,683	12,196	11,054	10,970	76.2	79.1	9.2	1,379	3,052	3,900	4,048	4,217
	Ct. 8	73.6	66.1	22.0	1,667	8,131	13,064	9,971	14,794	12,896	73.4	71.6	9.2	1,568	3,304	3,608	3,507	3,658
	Ct. 15	72.0	69.8	22.0	1,200	6,832	7,141	9,943	10,904	9,905	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 24	72.3	74.0	22.0	1,508	8,121	7,360	11,996	10,184	12,079	70.7	60.0	9.2	1,664	3,108	2,830	3,642	3,777
	Ct. 27	66.2	67.6	22.0	1,153	7,804	11,168	11,855	11,874	13,228	70.0	64.0	9.2	1,515	3,014	3,703	3,505	3,825
	Ct. 36	65.8	66.2	22.0	1,151	6,934	8,622	10,236	12,000	10,704	70.7	61.7	9.2	1,157	3,142	3,220	3,483	4,295
	Ct. 43	70.3	68.7	22.0	1,222	6,288	9,717	11,763	11,730	11,827	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 50	69.8	68.0	22.0	642	5,821	8,967	10,038	12,351	11,975	69.8	68.0	9.5	1,397	1,928	2,845	3,245	3,983
	Ct. 57	70.5	64.6	22.0	1,012	5,080	7,803	10,912	12,642	13,485	69.8	69.8	9.5	1,412	2,333	4,084	3,425	4,300
	Ct. 64	71.7	61.0	22.0	717	4,887	6,828	11,732	12,839	14,084	71.7	61.0	9.5	1,383	2,500	3,815	4,338	4,833
	Average	70.8	68.6	22.0	1,141	6,840	9,135	11,064	12,037	12,115	71.5	66.9	9.3	1,434	2,798	3,501	3,649	4,111

TABLE IIc.—*Compressive strengths of seven Portland cements and resulting mixtures, neat and in standard mortar*—Continued.

Brand.	Register No.	Neat.									1:3 standard-sand mortar.							
		Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).						Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch.)				
		Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.	Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
1	2	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
D	Ct. 5	77.1	80.2	21.0	.....	6,332	12,952	12,232	15,276	16,146	76.9	79.2	9.0	1,066	3,105	3,917	4,337	4,384
	Ct. 9	73.4	69.8	21.0	1,349	9,015	12,021	11,996	13,154	16,690	73.4	70.3	9.0	1,898	3,545	3,677	4,406	3,308
	Ct. 16	69.8	71.8	21.0	1,132	6,321	9,520	12,246	11,413	12,440	71.8	61.6	9.0	1,155	1,850	.....	.....	.....
	Ct. 25	69.1	68.0	21.0	1,831	9,511	12,874	11,281	12,719	11,430	70.7	60.0	9.0	1,845	3,233	2,689	2,909	3,375
	Ct. 30	63.5	59.0	21.0	605	6,623	9,375	12,138	12,538	16,386	70.0	64.0	9.0	1,290	3,344	3,363	2,825	3,100
	Ct. 37	59.6	60.1	21.0	684	4,896	12,134	14,266	16,560	10,814	70.7	61.7	9.0	919	3,625	3,641	4,600	7,275
	Ct. 44	73.8	69.1	21.0	569	5,946	10,206	11,215	14,864	13,375	70.7	68.0	9.3	1,448	1,813	3,267	3,117	3,908
	Ct. 51	69.0	68.0	21.0	518	3,442	8,439	12,253	14,788	13,141	70.7	69.8	9.3	1,448	1,621	2,762	3,318	3,892
	Ct. 58	71.6	69.9	21.0	617	5,319	9,531	10,388	12,944	12,664	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 65	71.7	61.0	21.0	525	4,264	6,996	10,811	13,064	12,987	70.7	69.8	9.3	730	2,033	3,681	3,700	4,200
	Average	69.9	67.7	21.0	876	6,166	10,405	11,883	13,731	13,607	71.7	67.2	9.1	1,311	2,637	3,375	3,652	4,180
E	Ct. 6	76.4	77.4	20.5	1,409	3,184	9,209	10,680	11,581	13,031	76.5	77.5	8.9	956	1,319	2,102	2,565	2,437
	Ct. 10	73.6	71.6	20.5	1,368	4,948	9,626	7,038	10,192	12,806	71.6	71.6	8.9	900	1,368	1,600	1,854	1,650
	Ct. 18	71.6	73.8	21.0	.....	4,957	6,119	8,804	9,644	11,363	71.8	61.6	9.0	923	1,754	2,322	.....	2,750
	Ct. 26	64.6	59.0	21.0	1,060	4,274	7,727	8,906	11,724	11,871	70.7	60.0	9.0	889	1,314	1,800	2,562	2,900
	Ct. 31	66.9	53.2	21.0	244	3,694	6,379	8,145	9,325	10,955	70.0	64.0	9.0	740	1,308	2,467	2,846	3,525
	Ct. 38	64.4	70.5	21.0	609	3,943	6,309	8,233	11,327	11,775	69.8	66.9	9.0	645	1,363	2,970	4,631	4,342
	Ct. 45	70.5	68.0	21.5	692	2,499	5,488	8,199	11,080	11,474	70.7	68.0	9.4	836	949	2,396	3,141	3,150
	Ct. 52	72.0	70.8	21.5	299	2,156	6,693	6,929	11,325	13,691	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 59	71.6	69.9	21.5	365	2,314	6,113	10,604	11,394	11,257	69.8	68.0	9.4	912	955	2,503	2,858	2,917
	Ct. 66	71.7	61.0	21.5	283	1,762	5,084	9,405	11,858	11,880	69.8	69.8	9.4	867	1,746	2,824	3,275	3,633
	Average	70.3	67.5	21.1	703	3,373	6,875	8,694	10,945	12,010	71.2	67.5	9.1	852	1,542	2,332	2,959	3,034
F	Ct. 11	71.6	71.8	21.5	1,380	5,859	8,448	9,039	9,170	7,725	71.8	61.6	9.1	1,119	1,653	.....	.....	.....
	Ct. 19	70.2	69.4	21.5	1,380	5,845	8,827	9,542	11,148	11,900	71.8	61.6	9.1	1,123	1,775	2,463	2,947	2,788
	Ct. 28	61.9	62.9	21.5	2,163	4,569	9,503	8,673	11,521	10,973	70.5	59.0	9.1	888	1,396	2,140	2,346	3,167
	Ct. 32	68.0	59.3	29.5	879	5,358	9,030	10,101	12,500	10,877	70.0	64.0	9.0	1,066	1,843	2,871	2,906	3,717
	Ct. 39	73.0	70.0	21.5	1,369	6,058	7,929	8,937	10,135	10,320	69.8	66.1	9.1	1,138	1,607	3,793	4,531	5,025
	Ct. 46	69.8	68.3	21.5	924	3,096	6,098	9,193	9,324	11,739	70.7	69.8	9.4	1,124	1,646	2,673	3,302	3,750
	Ct. 53	72.0	70.8	21.5	803	4,625	7,734	10,917	11,597	12,425	70.7	69.8	9.4	1,074	1,086	3,206	3,780	3,842
	Ct. 60	71.6	69.9	21.5	950	2,934	6,878	11,067	11,879	11,066	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 67	71.2	62.6	21.5	889	6,226	9,258	11,672	12,456	12,497	69.8	69.8	9.4	1,090	1,651	3,409	3,592	4,042
	Average	69.9	67.2	21.5	1,193	4,952	8,189	9,905	11,080	11,058	70.6	65.2	9.2	1,078	1,582	2,937	3,343	3,762

	Ct. 12	71.8	70.4	21.0	992	4,966	7,408	9,115	9,848	12,884	71.6	72.1	9.0	960	1,489	2,445	3,317	3,283
	Ct. 20	66.9	70.0	21.0	1,951	5,188	7,510	8,729	9,046	12,007	71.8	61.6	9.0	1,085	1,821	2,371	3,199	3,538
	Ct. 29	70.5	70.5	20.5	2,014	3,538	5,246	10,226	8,790	12,668	70.5	59.0	8.9	768	1,485	2,163	2,244	3,508
	Ct. 33	64.7	64.5	21.0	390	2,951	6,484	9,879	11,759	14,019	.....	.....	.....	.....	.....	.....	.....	.....
	Ct. 40	71.0	70.2	21.0	553	3,643	6,247	9,280	10,034	9,490	.....	.....	.....	.....	.....	.....	.....	.....
G	Ct. 47	69.8	68.3	20.5	253	3,355	5,186	9,177	9,954	13,511	70.7	68.0	9.4	907	1,294	2,661	3,818	4,383
	Ct. 54	72.0	70.8	20.5	353	3,574	5,268	6,800	10,464	12,648	69.8	68.0	9.3	1,003	1,282	2,361	3,212	4,133
	Ct. 61	69.8	68.0	20.5	867	2,863	4,785	7,605	11,512	12,151	69.8	69.8	8.8	929	1,209	2,497	2,688	4,158
	Ct. 68	71.2	62.5	20.5	862	4,102	5,186	8,541	11,947	13,807	.....	.....	.....	.....	.....	.....	.....	.....
	Average	69.7	68.4	20.7	915	3,798	5,924	8,817	10,373	12,576	70.7	66.4	9.1	942	1,430	2,416	3,080	3,834
	Average A-G	70.3	68.7	21.4	1,014	5,009	8,007	10,060	11,503	12,028	71.4	67.3	9.2	1,117	1,943	3,002	3,270	3,741
Mix. 1	Ct. 69	71.2	62.6	21.5	1,121	4,884	8,568	8,561	12,475	14,273	71.6	71.6	9.6	973	2,389	3,863	4,400	4,771
2	Ct. 70	70.8	68.5	22.5	793	5,195	7,006	11,050	11,623	13,247	71.6	71.6	9.6	925	1,721	1,598	3,725	4,238
3	Ct. 71	70.8	68.5	21.0	1,114	3,600	8,457	10,533	10,047	14,075	.....	.....	.....	.....	.....	.....	.....	.....
4	Ct. 72	70.8	68.5	21.5	918	5,275	8,505	10,734	10,993	12,456	71.6	71.6	9.4	1,006	1,755	3,369	3,975	4,047
5	Ct. 73	71.6	59.7	21.0	967	6,671	8,003	9,573	11,094	12,234	.....	.....	.....	.....	.....	.....	.....	.....
6	Ct. 74	71.6	59.7	23.0	1,057	4,039	8,579	10,334	12,359	12,146	71.6	64.4	9.6	959	2,133	3,538	4,050	4,525
7	Ct. 75	71.6	59.7	21.5	996	2,996	8,013	10,023	11,813	12,051	68.0	62.0	9.4	885	2,103	3,815	4,375	5,200
8	Ct. 76	71.4	67.6	23.0	1,103	4,400	7,087	9,699	12,362	12,607	68.0	62.0	9.4	846	2,209	3,201	3,608	4,500
9	Ct. 77	71.4	67.6	23.0	1,044	5,053	7,354	11,068	11,598	12,427	68.0	62.0	9.4	903	2,253	3,795	4,162	4,775
10	Ct. 78	71.4	67.6	23.0	632	4,459	7,627	11,759	10,663	12,837	.....	.....	.....	.....	.....	.....	.....	.....
	Average	71.3	65.0	22.0	975	4,657	7,920	10,333	11,503	12,835	70.1	66.5	9.5	928	2,059	3,311	4,042	4,579

Specific gravity.—The specific gravity was determined after heating a small quantity of cement to 212° F. for 5 hours. In subsequent work the samples will also be ignited. Values of specific gravity in the table vary from 3.100 to 3.195. The variation for any individual brand is much smaller than the total variation. The average of all seven brands is 3.120, while the average of the 10 mixes is 3.122.

Time of setting.—In the investigations of the time of setting, the temperature of the water and of the air at the time of molding, the percentage of water which was necessary to bring the cement to normal consistency, and the time of both the initial and final setting, as determined by both the Vicat and Gilmore apparatus, were determined and recorded.

The time elapsing before both initial and final set as determined by the Gilmore needle is in almost every case greater than that determined by the Vicat needle.

Fineness.—Of the 68 samples of the seven individual brands only a few reached as high as 25 per cent residue on the No. 200 sieve. Five brands, namely, A, C, D, E, and G, were found to be of approximately equal fineness.

Constancy of volume.—In order to determine the constancy of volume by the appearance of the pat, two normal and two accelerated tests were made of each sample. The normal tests consisted of the maintenance of pats in air and in water for 28 days at a temperature as nearly 70° F. as practicable. The accelerated tests consisted in keeping one pat exposed in an atmosphere of steam and another immersed in boiling water for 5 hours.

In all the accelerated tests and nearly all the normal tests the pats remained unaltered, the exceptions being noted in each case under "Soundness" (column 13, p. 13) in the table. Where the pats have passed all the forms of tests it is indicated by the phrase "Perfectly sound." Where the pats failed to pass the tests without change it is indicated by "Pat — warped — inch," the letter "A" being used for the 28-day normal air tests and "B" for the 28-day normal water tests.

Tensile strength.—Tensile and compressive tests were made of samples taken from each barrel, also from each of the 10 mixtures. These tests for both the neat cement and 1:3 standard-sand mortars (using Ottawa sand screened to 20–30 size) were made in sets of three at ages of 7, 28, 90, 180, and 360 days. For the neat cement a 1-day test was also made.

The results of the tensile tests are given in Table II*b* (p 16), each value being the average of three tests. All the tests of each individual brand are grouped together and given a single letter for identification. The register numbers in this table are the same as

those in Table I (p. 11), so that the results of tests of physical properties of any sample can be compared with the chemical analysis. The temperatures of the water and of the air given in this table are those observed at the time of making the test pieces. The percentage of water is that required to secure a normal consistency and was determined in advance in each case. At the bottom of each group

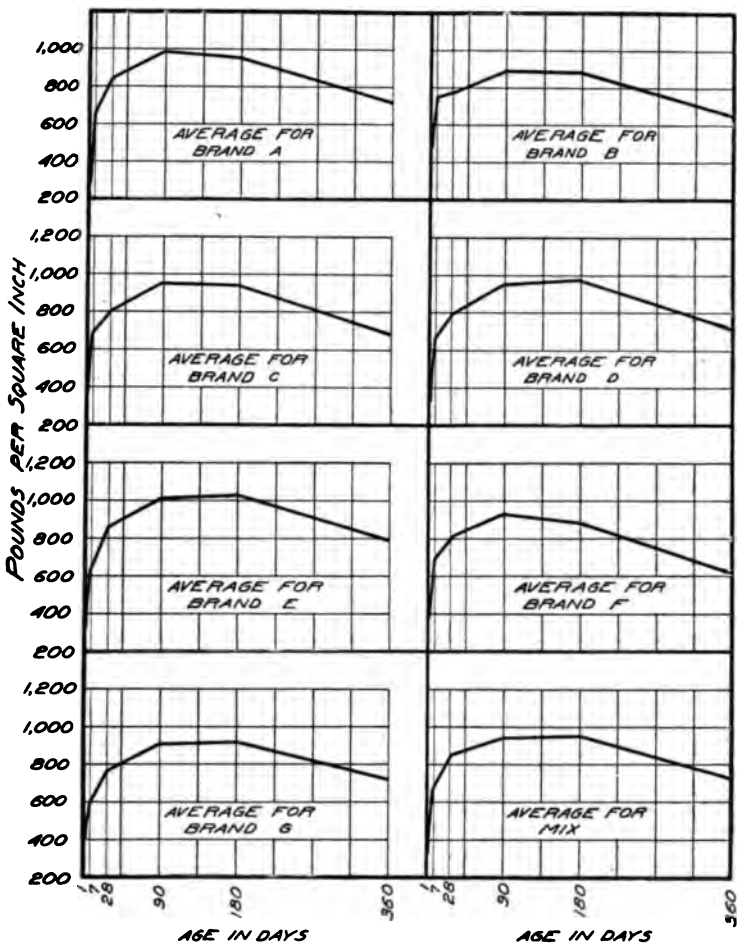


FIG. 1.—Curves showing variation of tensile strength with age of neat cement.

are given the average values for that brand and at the bottom of the table are given the averages for the 10 mixes. Between brand G and the mixes there is a line which gives the averages of all the 68 samples taken from the seven individual brands.

Effect of age on tensile strength.—The average results of tests to determine the effect of age on tensile strength for each individual brand and for the 10 mixes are plotted in figs. 1 and 2. Fig. 1

shows the results for neat cement and fig. 2 the results for 1:3 standard-sand mortar. In both these diagrams it is noticeable that there is an increase in strength up to 90 days, almost uniform strength from 90 to 180 days, and a decided falling off in almost every case to 360 days. It should be observed that in fig. 2 the curve showing the variation of strength with age of the average of the 10 mixes does

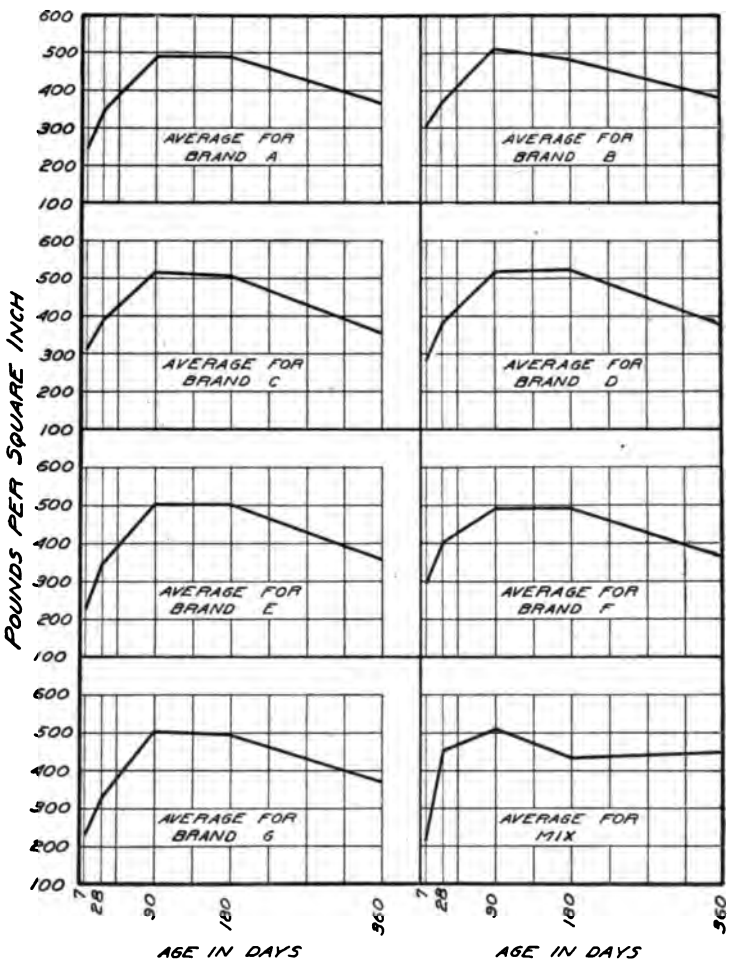


FIG. 2.—Curves showing variation of tensile strength with age of 1:3 standard-sand mortar.

not correspond exactly in shape to the curves for the seven brands. In this case the maximum strength is attained at 90 days ,and there is a falling off to 180 days. Afterwards the strength is almost constant to 360 days.

Compressive strength.—The results of the compressive tests of the cubes are given in Table IIc (p. 19). The register numbers being the

same, the compressive strength can be compared with the chemical composition, Table I (p. 11), and with the other physical properties in the preceding sections of Table II (pp. 13–18).

The irregularity in the results of the 1-day and 7-day compression tests of neat cement can probably be accounted for by the conditions in the laboratory while these tests were being made. The galvanized-iron cans that are now used for storing cement had not been procured in sufficient numbers at the time of mixing these test pieces, and a large amount was stored in sacks, where it was subject to the action of moisture in the air. The lack of a sufficient number of cube molds and the delay in obtaining sufficient Ottawa sand rendered it necessary to continue the molding of the test pieces over several months through the winter of 1905–6. Furthermore, the exposition buildings used by the laboratories were ill adapted for the work, and the installation of the necessary heating plant was not completed until after these tests were made. During this period the temperature frequently dropped at night as low as 40°, which retarded the hardening and reduced the early strength. In the tests at the end of 180 days the regularity and uniformity in the results seem to indicate that these early conditions had little effect on the final strength. The blank spaces in Table II indicate breaks in the series, where no test pieces were made, on account of the poor condition of the cement. No cement was tested if there was any indication of its having been injured by the moisture in the air.

The experience with the first cements was very valuable in indicating the care that should be taken in storing cement. At the present time the cement is dumped out of the sacks as soon as received, mixed in the cubical mixer, and stored in air-tight cans. As an additional precaution, all similar test pieces are molded at the same time. A complete heating system has now been installed, making it possible to control the temperature of the laboratories.

The temperatures given in this table are the temperatures of the water and of the air in the laboratory at the time of molding the test pieces. The neat test pieces and the 1:3 mortar test pieces were molded at different times, so different temperatures are given in the table. The percentage of water used in the test pieces was determined in advance.

The averages for each brand are given at the bottom of the group and the averages for the 68 tests on the individual brands are given near the bottom of the table, in the line marked "Average A–G." The averages for the 10 mixes are given at the bottom of the table.

Effect of age on compressive strength.—The results given in Table II are illustrated in figs. 3 and 4, for neat cement and 1:3 standard-sand mortar, respectively. In each of these figures the curves for

the seven brands and for the average of the 10 mixes are shown in separate diagrams. The difficulties already mentioned account for the difference between the curves in these two figures, which are greater than those for the tensile tests (figs. 1 and 2). These curves differ from the curves showing the variation in tensile strength with age, in that the compressive strength continues to increase up to 360

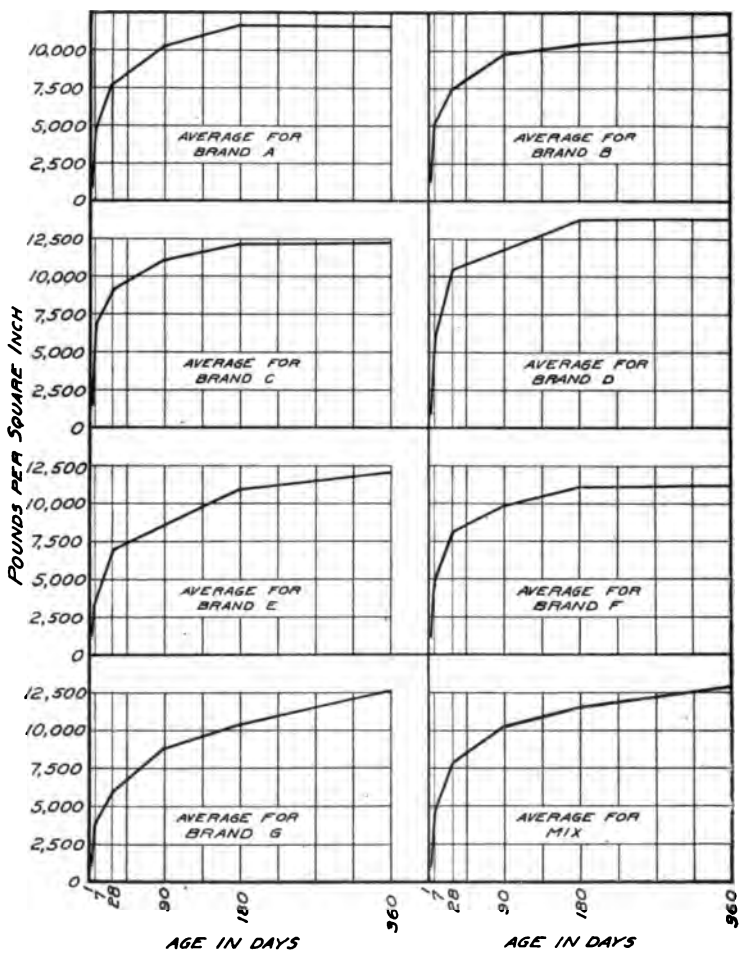


FIG. 3.—Curves showing variation of compressive strength with age of neat cement.

days, and the falling off noticed in the tension tests after 180 days is not apparent.

Percentage of gain in strength.—In order to determine the percentage of gain in strength from 7 to 28, from 7 to 90, from 7 to 180, and from 7 to 360 days for cements having different strengths at 7 days, Tables III, IV, V, and VI, based on the results given in the

preceding table, have been prepared, showing the tensile and compressive strengths of the different test pieces. The actual strengths are inserted for purposes of reference. The four right-hand columns in each table contain the percentages of gain. A round-number grouping is also shown, and at the bottom of each group the average strengths and average percentages are given.

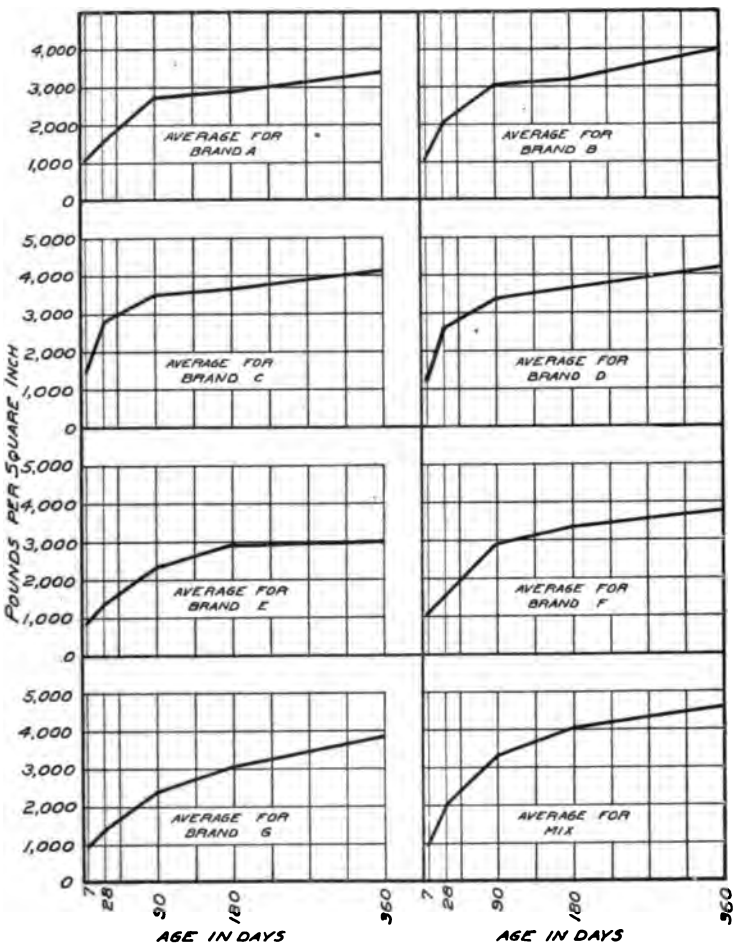


FIG. 4.—Curves showing variation of compressive strength with age of 1 : 3 standard-sand mortar.

Table III gives the percentage of gain in tensile strength of neat cement for the four periods named. The results are arranged consecutively in the order of the strength of the test pieces at 7 days, the lowest values being given first. It can readily be seen that for cement testing low at 7 days the increase in strength is much greater than for those testing high at 7 days.

TABLE III.—*Gain in tensile strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Below 550.	Ct. 34	534	831	994	896	645	56	86	68	21
	Ct. 61	543	766	936	878	810	41	72	62	49
	Ct. 59	550	823	1,010	1,052	888	50	84	91	61
	Average	542	807	980	942	781	49	81	74	44
Between 550 and 600.	Ct. 33	553	765	807	916	658	38	46	66	19
	Ct. 66	557	960	1,042	970	777	72	87	74	40
	Ct. 40	561	807	877	961	709	44	56	71	26
	Ct. 20	566	721	929	928	642	27	64	64	13
	Ct. 46	572	775	967	893	653	35	69	56	14
	Ct. 45	574	857	1,037	985	820	49	81	72	43
	Ct. 76	580	857	922	948	770	48	59	64	33
	Ct. 31	581	741	978	944	733	28	68	63	26
	Ct. 41	581	849	977	989	770	46	68	70	33
	Ct. 37	586	810	927	973	773	38	58	66	32
	Ct. 50	587	809	931	944	583	38	59	61	−1
	Ct. 54	589	715	905	865	725	21	54	47	23
	Ct. 38	590	907	1,033	1,071	815	54	75	82	38
	Ct. 52	593	839	950	1,042	864	41	60	76	76
	Ct. 55	599	810	943	914	673	35	57	53	12
	Average	578	815	948	956	731	41	64	65	26
Between 600 and 650.	Ct. 68	606	876	922	907	744	45	52	50	23
	Ct. 51	616	843	981	1,005	690	37	59	63	12
	Ct. 49	616	767	865	873	637	25	40	42	3
	Ct. 12	623	728	936	975	744	17	50	57	19
	Ct. 19	628	828	937	909	577	32	49	45	−8
	Ct. 47	636	736	930	955	774	16	46	50	22
	Ct. 62	637	766	981	955	752	20	54	50	18
	Ct. 75	644	846	998	988	718	31	55	53	11
	Ct. 18	645	936	1,050	1,055	689	45	63	64	7
	Ct. 48	646	884	940	965	664	37	46	49	3
	Ct. 44	649	787	958	962	710	21	48	48	9
	Average	631	818	954	959	700	30	51	52	11
Between 650 and 700.	Ct. 63	656	902	908	942	704	38	38	44	7
	Ct. 64	656	975	929	850	698	49	42	30	6
	Ct. 65	658	960	907	972	749	46	38	48	14
	Ct. 39	660	772	951	928	707	17	44	41	7
	Ct. 43	662	835	1,004	938	748	26	52	42	13
	Ct. 72	662	824	917	968	658	24	39	46	−1
	Ct. 29	663	810	916	846	653	22	38	28	−1
	Ct. 24	664	669	970	944	670	21	46	42	1
	Ct. 78	669	873	924	888	752	30	38	33	12
	Ct. 30	671	716	984	986	623	7	47	47	−7
	Ct. 58	674	804	1,017	973	817	19	51	44	21
	Ct. 17	676	844	909	857	741	25	34	27	10
	Ct. 11	676	751	926	873	659	11	37	29	−2
	Ct. 10	680	808	968	1,091	797	19	42	61	17
	Ct. 77	682	850	962	999	752	25	41	46	10
	Ct. 74	683	864	934	923	657	27	37	35	−4
	Ct. 57	684	851	949	916	644	24	39	34	−6
	Ct. 69	685	872	962	952	776	27	40	39	13
	Ct. 70	686	781	893	933	769	14	30	36	12
	Ct. 60	689	785	965	828	541	14	40	20	−21
	Ct. 27	699	803	958	962	603	15	37	38	−14
	Average	673	826	945	932	701	23	40	38	4
Between 700 and 750.	Ct. 16	701	604	984	967	648	14	40	38	−8
	Ct. 25	703	863	984	937	692	23	40	33	−2
	Ct. 26	707	914	985	984	712	29	39	39	1
	Ct. 71	708	870	954	966	712	23	35	36	1
	Ct. 9	709	753	750	911	695	6	6	28	−2
	Ct. 13	713	860	1,012	925	645	21	42	30	−10
	Ct. 21	714	862	989	937	686	21	39	31	−4
	Ct. 15	715	760	931	987	822	6	30	38	15
	Ct. 23	718	801	961	852	569	12	34	19	−21
	Ct. 56	724	759	880	898	618	5	22	24	−15
	Ct. 36	725	818	940	976	644	13	30	35	−11
	Ct. 1	726	769	988	947	806	6	36	30	−11
	Ct. 5	734	786	977	1,035	716	7	33	41	−2
	Ct. 32	736	717	735	821	616	−3	0	12	−16
	Ct. 53	738	865	951	962	627	17	29	30	−15
	Ct. 6	739	815	1,009	1,017	756	10	37	38	2
	Average	719	801	939	945	685	11	31	31	−5

TABLE III.—*Gain in tensile strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 750 and 800.	Ct. 8	754	748	916	905	646	− 1	21	20	−14
	Ct. 67	756	932	983	878	578	23	30	16	−24
	Ct. 4	760	785	942	962	687	3	24	27	−10
	Ct. 35	762	786	903	893	604	3	19	17	−21
	Ct. 42	764	673	907	857	726	−12	19	12	− 5
	Ct. 28	764	857	943	823	603	12	23	8	−21
	Ct. 22	766	727	863	638	651	− 5	13	−17	−15
	Ct. 73	771	878	921	929	663	14	19	20	− 14
	Ct. 2	783	926	1,103	1,079	772	18	41	38	− 1
	Average	764	812	942	885	659	6	23	16	−14
Above 800.	Ct. 3	820	725	955	955	669	−12	16	16	−18
	Ct. 14	821	833	861	1,042	659	− 1	5	27	−20
	Ct. 7	872	787	840	834	618	−10	− 4	− 4	−29
	Average	838	782	885	944	649	− 7	6	13	−23

Table IV gives the percentage of gain in tensile strength of 1:3 standard-sand mortar test pieces for the four periods. In this table also the gain for the test pieces testing low at 7 days is much greater than for the test pieces testing high at 7 days. The percentage of increase for the 1:3 standard-sand mortars appears to be much greater than for the neat cements.

TABLE IV.—*Gain in tensile strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Below 200.	Ct. 41	169	350	484	440	336	107	186	160	99
	Ct. 59	181	305	485	465	341	69	168	157	88
	Ct. 67	192	433	499	419	407	126	160	118	112
	Ct. 70	192	420	539	424	491	119	181	121	156
	Ct. 61	193	328	460	480	349	70	138	149	81
	Ct. 34	196	266	433	429	320	36	121	119	63
	Ct. 33	199	354	538	515	381	78	170	159	92
	Average	189	351	491	453	375	86	161	140	98
Between 200 and 250.	Ct. 45	204	313	510	488	343	53	150	139	68
	Ct. 38	205	367	496	520	359	79	142	154	75
	Ct. 74	206	415	439	423	437	101	113	105	112
	Ct. 75	206	448	464	450	466	117	125	118	126
	Ct. 71	208	472	481	418	473	127	131	101	127
	Ct. 40	209	321	487	471	327	54	133	125	57
	Ct. 52	211	323	508	533	334	53	141	153	58
	Ct. 76	212	463	557	413	430	118	163	95	103
	Ct. 65	215	474	513	443	500	120	139	106	133
	Ct. 77	217	463	560	446	439	113	158	106	102
	Ct. 47	222	365	490	499	381	64	121	125	72
	Ct. 31	232	363	478	515	346	56	106	122	49
	Ct. 62	233	327	515	505	318	40	121	117	37
	Ct. 10	235	376	504	439	349	60	114	87	49
	Ct. 55	241	391	475	501	351	62	97	108	46
	Ct. 30	242	379	525	557	344	57	117	130	42
	Ct. 6	243	334	506	527	361	37	108	117	49
	Ct. 17	244	410	468	577	366	68	92	136	50
	Ct. 54	247	355	525	534	369	44	113	116	49
	Ct. 69	248	491	527	455	466	98	113	84	88
	Ct. 46	249	415	503	491	354	67	102	97	42
	Average	225	394	501	486	386	76	124	116	72

TABLE IV.—*Gain in tensile strength of 1 : 3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Tensile strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 250 and 300.	Ct. 12	251	307	509	394	379	22	103	57	51
	Ct. 20	251	311	523	525	379	24	108	109	51
	Ct. 26	253	348	528	480	352	38	109	90	39
	Ct. 13	254	332	492	482	397	31	94	90	56
	Ct. 21	256	350	497	468	410	37	94	83	60
	Ct. 29	257	323	498	515	365	26	94	100	42
	Ct. 37	262	383	515	520	325	46	97	98	24
	Ct. 2	268	329	480	505	367	23	79	88	37
	Ct. 48	271	401	550	502	360	48	103	85	33
	Ct. 27	272	371	525	498	343	36	93	83	26
	Ct. 64	276	458	511	488	322	66	85	77	17
	Ct. 16	276	372	502	519	385	35	82	88	40
	Ct. 18	276	374	506	508	408	36	83	84	48
	Ct. 51	277	387	507	582	331	40	83	92	20
	Ct. 22	280	355	517	310	376	27	85	11	34
	Ct. 23	277	348	458	497	410	26	65	79	48
	Ct. 58	284	400	543	514	371	41	91	81	31
	Ct. 53	285	430	49	497	326	51	72	74	14
	Ct. 1	290	342	498	429	462	18	72	48	59
	Ct. 63	292	476	473	505	331	63	62	73	13
	Ct. 7	297	334	493	485	357	12	66	63	20
	Ct. 57	298	414	536	522	328	39	80	75	10
	Ct. 60	300	408	495	497	356	36	65	66	19
	Average	274	372	506	487	366	36	85	78	34
Between 300 and 350.	Ct. 9	301	368	511	511	369	22	70	70	23
	Ct. 8	302	351	491	456	352	16	63	51	17
	Ct. 36	303	392	536	518	351	29	77	71	16
	Ct. 44	304	341	527	501	391	12	73	65	29
	Ct. 42	306	404	568	520	348	32	86	70	14
	Ct. 50	307	397	525	527	358	29	71	72	17
	Ct. 14	308	349	510	486	416	13	66	58	35
	Ct. 43	309	392	517	506	374	27	67	64	21
	Ct. 3	310	323	510	522	354	4	65	68	14
	Ct. 28	310	396	457	466	359	28	47	50	16
	Ct. 19	313	435	465	477	391	39	49	52	25
	Ct. 25	315	403	504	488	398	28	60	55	26
	Ct. 32	315	389	507	495	339	23	61	57	8
	Ct. 49	317	409	555	506	355	29	75	60	12
	Ct. 56	319	370	508	507	382	16	59	59	20
	Ct. 5	322	345	541	545	360	7	68	69	12
	Ct. 39	323	411	500	518	332	27	55	60	3
	Ct. 35	323	386	529	485	415	20	64	50	29
	Ct. 24	324	393	492	511	379	21	52	58	17
	Ct. 11	341	364	516	478	396	7	51	40	16
	Ct. 15	349	372	509	512	359	7	46	47	3
	Average	315	380	513	502	370	21	63	59	17

Table V gives the percentage of gain in compressive strength of neat cement for the four periods named. In this case, also, it can be seen from the table that the percentage of gain for the test pieces testing low at 7 days is much greater than for the test pieces testing high at 7 days. The percentages of increase are greater in every case than those of tensile strength of neat cement or 1:3 standard-sand mortar.

TABLE V.—*Gain in compressive strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 2,000 and 3,000.	Ct. 55	2,138	6,114	9,194	9,500	11,318	186	330	344	430
	Ct. 52	2,156	6,693	6,929	11,325	13,691	210	221	426	535
	Ct. 59	2,314	6,113	10,604	11,394	11,257	164	358	392	387
	Ct. 45	2,499	5,488	8,199	11,080	11,474	120	228	344	359
	Ct. 61	2,863	4,785	7,605	11,512	12,152	67	166	302	324
	Ct. 60	2,934	6,878	11,067	11,879	11,066	134	277	305	277
	Ct. 33	2,951	6,484	9,879	11,759	14,019	120	235	299	375
	Ct. 75	2,996	8,013	10,023	11,813	12,050	167	235	295	302
	Average	2,606	6,321	9,188	11,203	12,128	146	256	331	366
Between 3,000 and 4,000.	Ct. 62	3,009	5,558	9,390	11,346	10,495	85	212	277	249
	Ct. 46	3,096	6,098	9,193	9,324	11,739	97	197	201	279
	Ct. 6	3,184	9,209	10,680	11,581	13,031	189	235	264	309
	Ct. 48	3,221	5,463	10,475	10,829	12,559	70	225	236	290
	Ct. 34	3,283	5,875	9,291	10,161	11,358	79	183	209	246
	Ct. 47	3,355	5,186	9,177	9,954	13,511	55	174	197	303
	Ct. 51	3,442	8,439	12,253	14,788	13,141	145	256	329	282
	Ct. 29	3,538	5,246	10,226	8,790	12,668	48	189	148	258
	Ct. 54	3,574	5,268	6,800	10,464	12,648	47	90	193	254
	Ct. 71	3,600	8,457	10,533	10,047	14,075	135	193	179	291
	Ct. 40	3,643	6,247	9,280	10,034	9,490	71	155	175	160
	Ct. 31	3,694	6,379	8,145	9,325	10,955	73	120	152	197
	Ct. 49	3,799	7,997	10,168	10,942	11,390	111	168	188	200
	Ct. 41	3,917	8,090	9,445	10,208	8,346	107	141	161	113
	Ct. 38	3,943	6,309	8,233	11,327	11,773	60	109	187	199
	Ct. 63	3,951	6,224	9,942	10,949	11,262	58	152	177	185
	Average	3,516	6,628	9,577	10,629	11,778	89	175	202	235
Between 4,000 and 5,000.	Ct. 74	4,039	8,579	10,334	12,359	12,146	112	156	206	201
	Ct. 68	4,102	5,186	8,541	11,947	13,807	26	108	191	237
	Ct. 65	4,254	6,996	10,811	13,064	12,987	64	154	207	205
	Ct. 26	4,274	7,727	8,906	11,724	11,871	81	108	174	178
	Ct. 76	4,400	7,087	9,699	12,362	12,607	61	120	181	187
	Ct. 78	4,459	7,627	11,759	10,663	12,865	71	164	139	189
	Ct. 42	4,563	8,656	11,531	11,150	11,449	90	153	144	151
	Ct. 28	4,569	9,503	8,673	11,521	10,973	108	90	152	140
	Ct. 53	4,625	7,734	10,917	11,597	12,425	67	136	151	169
	Ct. 69	4,884	8,568	8,561	12,475	14,273	75	75	155	192
	Ct. 64	4,887	6,828	11,732	12,839	14,084	40	140	163	188
	Ct. 37	4,896	12,134	14,266	16,550	10,814	148	191	238	121
	Ct. 18	4,957	6,119	8,804	9,644	11,363	23	78	94	129
	Ct. 56	4,946	8,470	8,979	10,662	13,774	71	82	116	179
	Ct. 10	4,948	9,626	7,038	10,192	12,806	95	42	106	159
	Ct. 13	4,957	8,308	8,653	12,176	13,033	68	75	146	163
	Ct. 12	4,966	7,408	9,115	9,848	12,825	49	84	98	160
	Average	4,631	8,033	9,901	11,810	12,597	73	115	155	172
Between 5,000 and 6,000.	Ct. 77	5,053	7,354	11,068	11,598	12,477	46	119	130	147
	Ct. 57	5,080	7,803	10,912	12,642	13,485	54	115	149	166
	Ct. 20	5,188	7,510	8,729	9,046	12,007	45	68	74	131
	Ct. 72	5,275	8,505	10,734	10,993	12,456	61	104	108	136
	Ct. 70	5,195	7,006	11,050	11,623	13,247	35	113	124	155
	Ct. 58	5,319	9,531	10,388	12,944	12,664	79	95	144	138
	Ct. 32	5,358	9,030	10,101	12,500	10,877	69	89	134	103
	Ct. 22	5,545	7,191	9,055	10,360	10,896	30	63	87	97
	Ct. 35	5,717	9,426	10,301	11,421	11,384	65	80	100	99
	Ct. 50	5,821	8,967	10,038	12,351	11,978	54	72	112	106
	Ct. 19	5,845	8,827	9,542	11,138	11,900	51	63	91	104
	Ct. 11	5,859	8,448	9,039	9,170	7,725	44	54	57	32
	Ct. 44	5,946	10,206	11,215	14,864	13,375	72	89	150	125
	Ct. 7	5,994	6,311	9,746	10,106	11,094	5	63	69	85
	Ct. 14	5,996	8,559	8,497	8,927	9,338	43	42	49	56
	Average	5,546	8,312	10,028	11,313	11,660	58	82	104	110
Between 6,000 and 7,000.	Ct. 39	6,058	7,929	8,937	10,135	10,320	31	48	67	71
	Ct. 2	6,084	9,427	12,319	13,367	12,618	55	102	120	108
	Ct. 23	6,209	6,468	9,504	9,511	10,073	4	53	53	62
	Ct. 67	6,226	9,258	11,672	12,456	12,497	49	87	100	101
	Ct. 43	6,288	9,717	11,763	11,730	11,827	55	87	87	88
	Ct. 16	6,321	9,520	12,246	11,413	12,440	51	94	81	97
	Ct. 5	6,332	12,952	12,232	15,276	16,146	105	93	141	155
	Ct. 1	6,371	8,531	13,237	15,292	11,631	34	108	140	83

TABLE V.—*Gain in compressive strength of neat cement from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 6,000 and 7,000.	Ct. 17	6,402	9,724	11,334	12,653	12,756	52	77	98	99
	Ct. 30	6,623	9,375	12,138	12,538	16,386	42	83	89	147
	Ct. 73	6,671	8,003	9,573	11,094	12,234	20	44	66	83
	Ct. 15	6,832	7,141	9,943	10,904	9,905	5	46	60	45
	Ct. 36	6,934	8,622	10,236	12,000	10,704	24	48	73	55
	Ct. 21	6,961	8,877	9,369	10,888	11,537	28	35	56	66
	Average	6,451	8,967	11,036	12,090	12,219	40	72	87	89
Above 7,000.	Ct. 27	7,804	11,168	11,855	11,874	13,228	43	52	52	70
	Ct. 8	8,131	13,064	9,971	14,794	12,896	61	23	82	59
	Ct. 4	8,503	10,683	12,196	11,054	10,970	26	43	30	29
	Ct. 9	9,015	12,021	11,996	13,154	16,690	33	33	46	85
	Ct. 25	9,511	12,874	11,281	12,719	11,430	35	19	34	20
	Average	8,593	11,962	11,460	12,719	13,043	40	34	48	51

Table VI gives the percentage of gain in the compressive strength of 1:3 standard-sand mortar for the four periods. Although the percentage of gain for the test pieces testing high at 7 days is less than for those that test low at 7 days, a very large increase is still shown throughout this table.

TABLE VI.—*Gain in compressive strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days.*

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Below 800.	Ct. 34	594	1,554	2,344	2,609	3,988	162	295	338	571
	Ct. 38	645	1,363	2,970	4,631	4,342	111	360	617	573
	Ct. 65	730	2,033	3,681	3,700	4,200	178	404	393	475
	Ct. 31	740	1,308	2,467	2,846	3,525	77	233	284	376
	Ct. 29	768	1,485	2,163	2,244	3,575	93	182	192	366
	Average	695	1,549	2,725	3,206	3,926	124	295	361	465
Between 800 and 900.	Ct. 45	836	949	2,396	3,141	3,150	14	187	276	277
	Ct. 76	846	2,209	3,201	3,608	4,500	161	278	326	432
	Ct. 66	867	1,746	2,824	3,275	3,633	101	226	278	319
	Ct. 75	885	2,103	3,813	4,375	5,200	138	331	394	488
	Ct. 28	888	1,396	2,140	2,346	3,167	57	141	164	257
	Ct. 26	889	1,314	1,800	2,562	2,900	48	102	188	226
	Ct. 10	900	1,368	1,600	1,854	1,650	52	78	106	83
	Average	873	1,584	2,539	3,023	3,457	82	192	246	296
Between 900 and 1,000.	Ct. 77	903	2,253	3,795	4,162	4,775	150	320	361	429
	Ct. 47	907	1,294	2,661	3,818	4,383	43	193	321	383
	Ct. 59	912	955	2,503	2,858	2,917	5	174	213	220
	Ct. 37	919	3,125	3,641	4,600	7,275	240	296	292	692
	Ct. 18	923	1,754	2,322	.....	2,750	90	152	.....	198
	Ct. 61	929	1,209	2,497	2,688	4,158	30	169	189	343
	Ct. 74	959	2,133	3,538	4,050	4,495	122	269	322	370
	Ct. 6	956	1,319	2,102	2,505	2,437	38	120	162	155
	Ct. 12	960	1,489	2,445	3,317	3,283	55	155	246	242
	Ct. 69	973	2,239	3,863	4,400	4,771	130	297	352	390
	Ct. 56	982	2,850	3,542	3,267	4,675	190	261	243	376
	Ct. 2	985	1,776	2,439	2,617	2,367	80	148	166	140
	Average	942	1,866	2,946	3,480	4,024	98	213	269	327

TABLE VI.—*Gain in compressive strength of 1:3 standard-sand mortar from 7 to 28, 7 to 90, 7 to 180, and 7 to 360 days*—Continued.

Pounds per square inch at 7 days.	Register No.	Compressive strength (pounds per square inch).					Per cent of gain (based on strength at 7 days).			
		7 days.	28 days.	90 days.	180 days.	360 days.	7-28 days.	7-90 days.	7-180 days.	7-360 days.
Between 1,000 and 1,100.	Ct. 54	1,003	1,282	2,361	3,212	4,133	28	135	220	312
	Ct. 72	1,006	1,755	3,369	3,975	4,044	74	235	295	302
	Ct. 13	1,022	1,633	3,213	3,611	3,125	60	214	253	206
	Ct. 7	1,048	1,751	2,228	2,435	3,367	67	113	132	231
	Ct. 5	1,066	3,105	3,917	4,337	4,384	191	267	307	312
	Ct. 32	1,066	1,843	2,871	2,906	3,717	73	169	173	243
	Ct. 63	1,069	2,596	3,651	3,667	4,308	143	241	243	303
	Ct. 53	1,074	1,086	3,205	3,780	3,842	1	198	252	258
	Average	1,044	1,881	3,102	3,490	3,865	80	197	234	270
Between 1,100 and 1,200.	Ct. 49	1,103	1,245	2,497	3,117	2,642	13	126	183	139
	Ct. 11	1,119	1,653	.....	.....	.....	48	.....	.....	.....
	Ct. 19	1,123	1,775	2,463	2,947	2,788	58	119	162	148
	Ct. 46	1,124	1,646	2,673	3,302	3,750	46	138	194	234
	Ct. 35	1,131	1,459	3,093	3,725	4,067	29	173	229	213
	Ct. 39	1,138	1,607	3,793	4,531	5,025	41	233	298	342
	Ct. 22	1,152	2,369	3,174	2,794	4,750	106	176	143	312
	Ct. 16	1,155	1,850	.....	.....	.....	60	.....	.....	.....
	Ct. 36	1,157	3,142	3,220	3,483	4,292	172	178	201	271
	Ct. 41	1,184	1,298	2,870	3,045	3,208	10	142	157	171
	Average	1,139	1,804	2,973	3,368	3,815	58	161	196	235
Between 1,200 and 1,500.	Ct. 17	1,287	1,521	2,603	2,375	4,012	18	102	84	213
	Ct. 30	1,290	3,344	3,363	2,825	3,100	159	161	119	140
	Ct. 21	1,328	1,554	2,918	3,008	3,687	17	120	127	178
	Ct. 4	1,379	3,052	3,900	4,048	4,217	121	183	201	206
	Ct. 64	1,383	2,500	3,815	4,338	4,833	81	176	214	250
	Ct. 50	1,397	1,928	2,845	3,245	3,983	38	104	132	185
	Ct. 57	1,412	2,333	4,084	3,425	4,300	65	189	113	205
	Ct. 44	1,448	1,813	3,267	3,117	3,908	25	126	115	170
	Ct. 51	1,448	1,621	2,762	3,318	3,892	12	91	129	169
	Average	1,375	2,185	3,284	3,300	3,992	60	129	140	190
Above 1,500.	Ct. 27	1,515	3,014	3,703	3,505	3,825	99	144	131	153
	Ct. 8	1,568	3,304	3,608	3,507	3,658	111	130	124	133
	Ct. 24	1,664	3,108	2,830	3,642	4,042	87	70	119	143
	Ct. 25	1,845	3,293	2,689	2,909	3,375	78	46	58	83
	Ct. 9	1,898	3,545	3,677	4,405	3,475	87	94	132	183
	Average	1,698	3,253	3,301	3,594	3,675	92	97	112	116

A study of Table II (pp. 13–21) reveals the very important fact that no matter whether the cements test low or high at 7 days, and despite the varying percentages of increase for the four periods, the 180-day and the 360-day strengths are all reasonably close to one another. This fact shows that early strengths may vary considerably without seriously affecting the later strength of the cement or mortar.

The percentages of gain given in Tables III, IV, V, and VI are illustrated graphically in fig. 5. The strength in pounds per square inch at 7 days is plotted horizontally and the average percentage of increase in strength for each group of three is plotted vertically. The decrease in every case in the percentage of gain with the increase in strength at 7 days is readily apparent from these curves, which are plotted from the averages of about 5,000 tests, and serves to indicate probable strengths for periods beyond the 7-day strengths.

STRENGTH TESTS OF TYPICAL PORTLAND CEMENTS USED IN TESTS OF MORTARS OF SAND, OF GRAVEL SCREENINGS, AND OF STONE SCREENINGS.

Method of tests.—After the molding of the test pieces of the seven individual brands and of the 10 mixes was finished the typical Portland cement was mixed with varying proportions of the various sands, gravel screenings, and stone screenings. In every case when a set

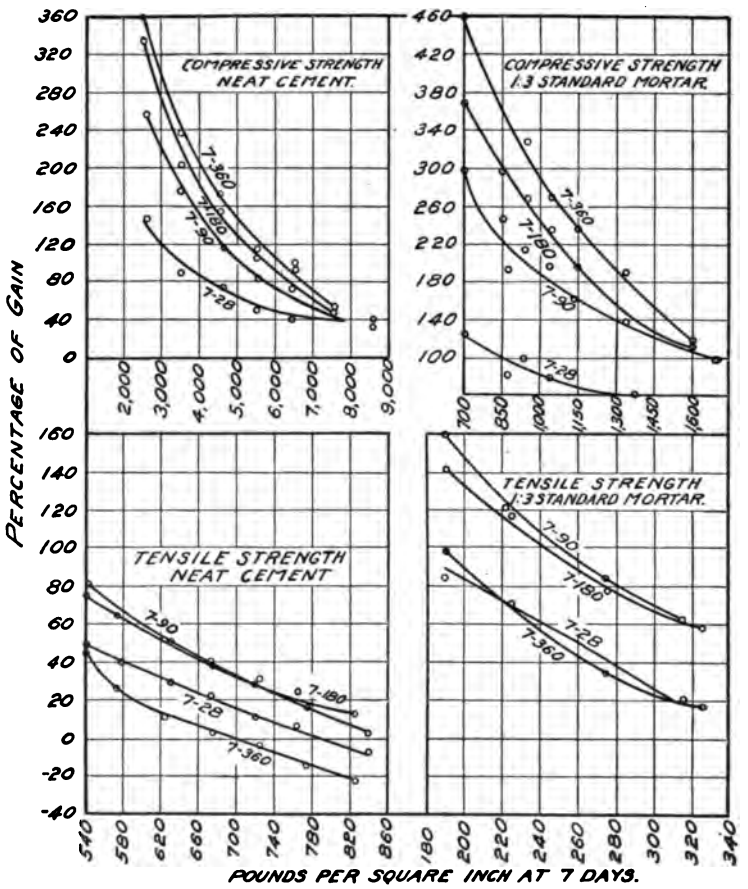


FIG. 5.—Gain in tensile and compressive strengths of neat cement and 1 : 3 standard-sand mortar, at 28, 90, 180, and 360 days; percentages based on strength at 7 days.

of mortar test pieces was made a set of neat-cement test pieces was also made at the same time from the same cement for tension, compression, and transverse tests, in order to afford a basis of comparison between the strengths of the different mortars. In order to identify the parallel cement tests, the register numbers of the sample used in these tests were given in the mortar tables opposite the register numbers of the materials with which they were used.

Tensile strength.—The results of the tension tests are given in Table VII*a*, each value being the average of three tests. The first mixture of seven brands was given the register number Ct. 79, and all samples taken from this were given the same register number and a second number to indicate the number of the sample. For example,

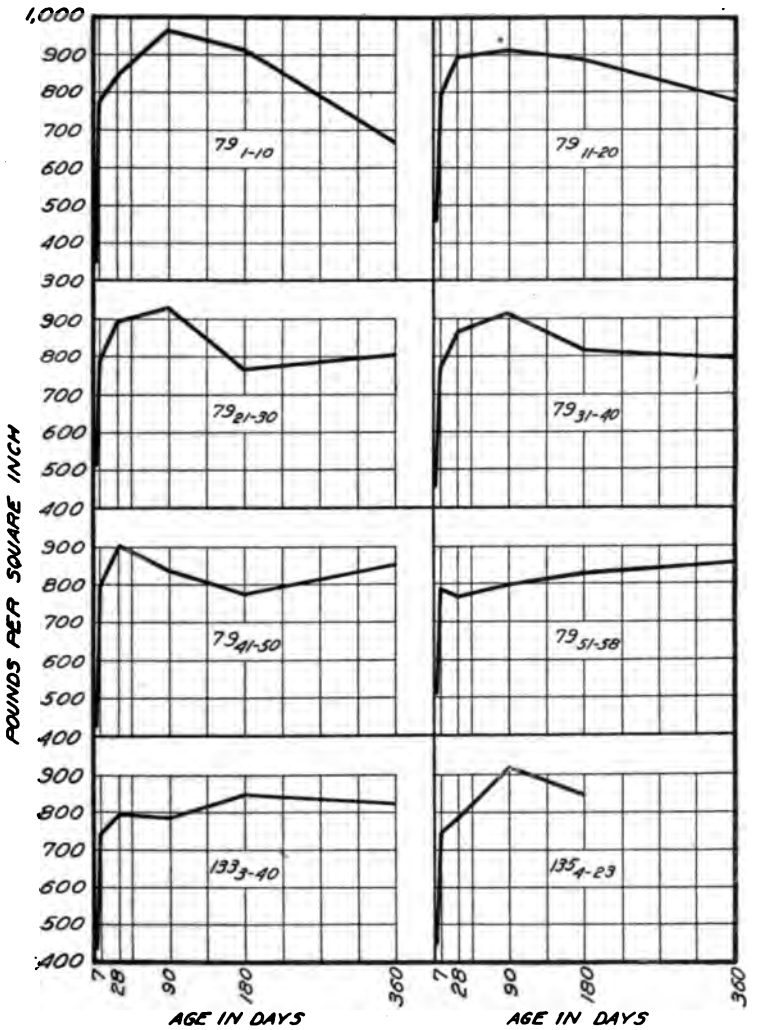


FIG. 6.—Curves showing variation of tensile strength with age of typical Portland cement.

the first register number given in Table VII*a* is Ct. 79–1, the next Ct. 79–2, etc., and so also for Tables VII*b* and VII*c*.

Table VII*a* affords an opportunity to study the effect of storage in air-tight cans on the tensile strength of the typical Portland cement used in the mortars. The results given near the top were

obtained from samples taken from the can early in the work, those given near the end of the table being obtained almost a year later. The cement used in the later tests was approximately one year older than that used in the first tests.

The variation of strength of these tensile-test pieces with age is shown in fig. 6, each of the separate averages being represented by an individual curve. The curves shown in fig. 6 are less uniform and not so much alike as those in fig. 1 (p. 23).

TABLE VIIa.—*Tensile strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Tensile strength (pounds per square inch.)					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-1	66.2	67.6	21.5	417	777	870	912	949	727
79-2	63.5	59.0	21.5	294	650	917	973	863	549
79-3	66.9	53.2	21.5	278	698	851	977	952	721
79-4	68.0	59.3	21.5	330	788	890	934	911	720
79-5	66.2	66.2	21.5	282	803	697	1,006	959	656
79-6	65.8	64.1	21.5	325	767	861	1,000	902	636
79-7	66.2	66.5	21.5	305	814	805	948	869	666
79-8	65.8	66.2	21.5	368	813	831	990	871	652
79-9	63.6	51.4	21.5	348	761	823	967	897	681
79-10	59.8	69.4	20.5	438	847	916	952	979	678
Average	65.2	62.3	21.4	339	772	846	966	915	669
79-11	74.0	70.0	20.5	500	733	852	955	996	716
79-12	71.5	68.0	20.5	472	788	864	958	931	638
79-13	70.5	68.0	20.5	456	772	897	965	867	716
79-14	71.6	68.0	20.5	422	843	790	1,018	833	713
79-15	71.0	69.0	20.5	379	769	887	813	858	788
79-16	71.6	59.7	20.5	461	821	886	817	865	823
79-17	71.2	67.6	20.5	532	810	949	918	849	856
79-18	69.0	68.9	20.5	525	823	982	903	942	825
79-19	74.8	66.2	20.5	374	823	954	811	927	868
79-20	69.8	67.2	20.5	392	749	859	967	823	845
Average	71.5	67.3	20.5	451	793	892	913	889	779
79-21	70.5	54.3	20.5	433	806	914	909	860	782
79-22	71.6	68.2	20.5	517	822	954	968	859	788
79-23	71.2	68.0	20.5	560	949	987	923	842	835
79-24	70.7	52.0	20.5	427	790	909	912	665	828
79-25	71.6	73.4	20.5	568	766	831	890	773	821
79-26	69.8	68.0	20.5	546	778	948	943	738	755
79-27	70.7	64.4	20.5	577	757	922	958	727	825
79-28	71.0	59.2	20.5	577	707	939	990	762	797
79-29	70.7	70.7	20.5	483	803	793	899	705	782
79-30	70.7	70.5	20.5	539	774	748	903	736	811
Average	70.9	64.9	20.5	513	795	895	930	767	802
79-31	70.7	70.0	20.5	542	837	904	907	945	827
79-32	70.7	62.6	20.5	500	803	890	921	827	737
79-33	69.8	63.0	20.5	506	738	693	860	836	665
79-34	69.8	69.8	20.5	522	697	780	972	860	833
79-35	70.0	70.4	20.5	293	927	836	829	844	811
79-36	68.0	68.9	20.5	506	808	923	927	778	798
79-37	68.0	68.4	20.5	377	660	963	950	924	808
79-38	69.8	68.0	20.5	396	745	838	856	708	831
79-39	71.5	70.0	20.5	521	725	894	925	861	815
79-40	69.8	70.0	20.5	398	761	948	966	754	815
Average	69.8	68.1	20.5	456	770	867	911	814	794
79-41	68.0	64.4	20.5	321	720	909	753	718	841
79-42	69.8	64.4	20.5	309	787	864	872	660	854
79-43	68.0	68.0	20.5	371	789	936	867	815	851
79-44	68.0	62.6	20.5	447	641	972	825	776	805
79-45	68.0	64.4	20.5	351	761	903	938	772	852
79-46	71.6	71.6	20.5	521	817	903	823	848	863
79-47	68.0	64.4	20.5	452	800	851	747	719	827
79-48	69.8	66.2	20.5	498	854	854	834	778	827
79-49	68.0	67.1	20.5	583	853	924	745	796	876
79-50	69.8	59.0	20.5	427	899	944	943	823	900
Average	68.9	65.2	20.5	423	792	906	835	771	850

TABLE VIIa.—*Tensile strength of typical Portland cement used in mortar tests*—Cont'd.

Register No.	Temperature (° F.).		Water (per cent).	Tensile strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-51	69.8	62.0	20.5	494	819	851	827	825	859
79-52	69.8	68.0	20.5	510	852	762	837	776	862
79-53	69.8	66.2	20.5	509	624	723	765	833	841
79-54	69.8	72.5	20.5	514	867	731	780	832	857
79-55	69.8	68.0	20.5	537	848	733	812	786	879
79-56	71.6	64.2	20.5	536	835	804	657	846	866
79-57	71.6	64.2	20.5	488	757	803	888	841	847
79-58	69.8	65.4	20.5	465	672	728	815	874	852
Average	70.3	66.7	20.5	507	784	767	798	827	858
133-3	63.0	67.1	20.5	383	708	867	837	789	863
133-5	68.0	78.8	20.5	425	684	784	769	844	880
133-17	68.9	67.1	20.5	491	748	787	826	882	722
133-21	69.8	78.8	20.5	437	725	815	715	960	697
133-23	69.8	64.0	20.5	329	764	749	677	769	877
133-28	68.0	66.2	20.5	476	768	772	862	853	843
133-40	71.6	71.6	20.5	487	780	798	834	804	861
Average	68.4	70.5	20.5	433	740	796	789	843	820
135-4	78.8	82.4	.....	467	740	690	960	858	.....
135-14	78.8	77.0	20.5	377	652	816	971	830	.....
135-20	77.9	74.3	.....	480	794	819	886	870	.....
135-23	78.8	72.5	20.5	418	788	831	862	823	723
Average	78.6	76.5	20.5	436	744	789	920	845	.....

Compressive strength.—The results of the compression tests are given in Table VII*b*, each value being the average of three tests. The foregoing remarks with regard to storage apply equally well to the samples used in the compression tests. The variation in strength of the compressive-test pieces with age is shown in fig 7 (p. 39), each of the separate averages being represented by an individual curve. These curves are less uniform than those shown in fig. 3 (p. 26).

TABLE VII*b*.—*Compressive strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-1	69.0	68.7	21.5	2,946	8,284	10,068	11,409	12,792	14,664
79-2	74.8	66.2	21.5	2,479	8,671	10,033	10,716	12,774	16,286
79-3	69.8	67.6	21.5	1,896	7,696	11,475	11,793	12,658	13,184
79-4	71.6	55.0	21.5	2,635	8,607	10,539	11,129	14,392	14,098
79-5	70.0	64.4	21.5	3,048	7,103	9,714	11,861	13,073	12,422
79-6	69.6	60.3	21.5	2,915	6,767	8,300	11,462	12,671	14,113
79-7	70.5	54.3	21.5	3,001	7,561	9,724	12,730	12,000	12,982
79-8	71.6	68.2	21.5	4,203	7,071	10,813	12,489	12,473	11,583
79-9	71.2	68.0	21.5	2,367	6,778	11,245	11,143	11,917	11,333
79-10	70.7	52.0	20.5	2,344	7,233	9,892	13,308	14,289	14,418
Average	70.9	62.5	21.4	2,783	7,577	10,280	11,804	12,904	13,508
79-11	73.4	57.2	20.5	2,586	7,717	9,132	11,842	14,065	12,583
79-12	68.0	60.8	20.5	3,044	6,895	8,284	11,220	13,229	13,014
79-13	68.0	73.4	20.5	2,855	7,648	8,699	12,738	11,838	13,218
79-14	70.7	69.0	20.5	3,075	6,688	10,761	12,008	13,933	14,007
79-15	69.8	70.0	20.5	3,093	7,240	10,573	12,684	13,342	12,326
79-16	70.7	70.0	20.5	3,216	7,036	10,232	12,448	13,515	14,743
79-17	70.2	69.8	20.5	3,351	7,467	9,570	11,246	9,893	14,243
79-18	68.0	66.2	20.5	3,726	7,428	9,640	13,890	10,288	12,045
79-19	69.8	66.2	20.5	3,885	8,838	9,870	12,090	12,101	11,841
79-20	69.8	72.0	20.5	3,848	8,000	9,111	10,963	14,494	13,251
Average	69.8	67.5	20.5	3,268	7,496	9,587	12,113	12,670	13,127

TABLE VIIb.—*Compressive strength of typical Portland cement used in mortar tests*—Cont'd.

Register No.	Temperature (° F.).		Water (per cent).	Compressive strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
79-21	69.8	68.0	20.5	4,277	8,568	9,008	10,675	11,188	12,969
79-22	70.7	64.4	20.5	3,954	7,684	11,229	11,488	11,164	12,664
79-23	73.4	71.6	20.5	3,988	8,006	10,595	10,516	11,881	14,169
79-24	70.7	62.6	20.5	2,794	7,675	10,235	12,421	13,534	10,914
79-25	68.9	69.8	20.5	3,850	7,533	9,463	10,364	11,342	16,546
79-26	70.7	69.0	20.5	3,721	8,089	10,228	11,253	14,071	12,113
79-27	70.7	66.2	20.5	3,010	7,300	9,667	13,174	13,117	13,116
79-28	69.8	63.0	20.5	3,148	6,542	11,091	13,388	13,693	11,204
Average	70.6	66.4	20.5	3,593	7,675	10,190	11,660	12,499	12,962
79-34	70.7	60.8	20.5	2,888	6,301	10,189	12,969	13,474	12,415
79-35	70.0	70.0	20.5	3,679	7,383	11,871	13,204	13,546	11,124
79-36	68.0	70.7	20.5	3,546	7,103	10,435	10,820	11,472	11,980
79-37	69.8	70.0	20.5	3,188	7,846	9,957	10,875	11,688	12,906
79-38	68.0	68.0	20.5	3,276	7,333	8,501	11,159	13,863	13,654
79-39	69.8	67.1	20.5	2,312	8,247	10,379	12,532	14,362	12,947
79-40	71.6	71.6	20.5	4,617	7,102	10,228	10,674	12,188	14,084
Average	69.7	68.3	20.5	3,358	7,331	10,223	11,748	12,942	12,725
79-41	68.0	64.4	20.5	.....	5,859	10,157	.....	.....	.....
79-42	68.0	68.0	20.5	1,800	7,729	11,036	11,112	13,216	13,856
79-43	64.4	64.4	20.5	2,598	8,046	10,439	10,468	14,706	15,667
79-44	68.0	64.4	20.5	2,707	6,669	10,721	11,425	12,955	14,725
79-45	68.0	64.4	20.5	2,726	7,388	9,925	10,596	8,507	14,392
79-46	68.0	64.4	20.5	2,634	7,061	11,179	10,623	11,148	14,441
79-47	69.8	62.6	20.5	3,474	7,738	10,732	12,863	8,150	13,992
79-48	68.8	62.6	20.5	2,963	7,963	11,425	12,221	10,458	13,377
79-49	68.0	67.1	20.5	3,321	7,480	11,037	13,331	13,056	14,098
79-50	69.8	60.0	20.5	2,637	7,913	10,464	11,957	11,609	13,322
Average	68.1	64.2	20.5	2,762	7,385	10,712	11,622	11,534	14,208
79-51	69.8	69.8	20.5	4,224	3,800	9,960	11,606	12,469	14,414
79-52	68.9	69.2	20.5	3,258	7,677	12,096	13,304	11,794	13,837
79-53	69.8	68.0	20.5	4,798	8,456	10,391	12,389	12,488	13,483
79-54	69.8	65.3	20.5	2,962	8,425	10,621	13,640	11,318	14,203
79-55	69.8	68.0	20.5	3,929	7,835	11,278	12,942	13,129	14,266
79-56	71.6	67.1	20.5	4,868	8,678	9,889	10,935	10,916	14,424
79-57	69.8	64.2	20.5	2,552	8,446	11,046	10,985	11,326	14,393
Average	69.9	67.2	20.5	3,799	8,268	10,754	12,257	11,920	14,146
133-3	63.5	74.0	20.5	5,157	8,018	8,875	10,788	10,707	14,579
133-5	67.1	68.0	20.5	4,505	8,299	8,609	12,204	13,118	14,457
133-17	68.9	77.0	20.5	5,188	7,844	8,174	11,381	13,033	15,645
133-21	69.8	73.4	20.5	4,374	7,471	9,843	11,818	11,423	13,343
133-23	68.9	68.0	20.5	3,445	8,372	11,869	13,286	11,410	14,576
133-28	68.9	74.3	20.5	4,998	6,591	8,104	11,617	10,023	14,147
133-40	71.6	69.8	20.5	4,192	7,240	9,585	12,996	10,444	14,814
Average	68.4	72.1	20.5	4,551	7,691	9,293	12,013	11,451	14,509
135-1	68.0	64.4	20.5	2,549	7,043	9,484	10,464	14,235	13,026
135-5	78.8	80.6	.....	4,443	7,250	9,051	11,691	11,806	.....
135-14	78.8	75.2	.....	4,967	8,305	10,333	10,185	12,976	.....
135-20	77.9	74.3	.....	4,925	8,296	8,626	12,096	12,716	.....
135-23	78.8	72.5	20.5	4,312	6,625	11,553	11,196	12,716	.....
135-24	78.8	71.6	11.5	5,062	7,675	9,282	11,767	12,847	.....
135-25	78.8	71.6	10.0	5,062	7,667	9,282	.....	11,848	.....
135-26	78.8	71.6	11.0	5,062	7,667	9,282	11,767	.....	.....
Average	77.3	72.7	14.7	4,548	7,566	9,612	11,309	12,738	.....

Transverse strength.—The results of the transverse tests are given in Table VII*c*, each value being the average of three tests. The values in the table are the moduli of rupture computed from the breaking load at the center by means of the formula $s=\frac{Mc}{I}$. The results given in this table are shown graphically in fig. 8. These

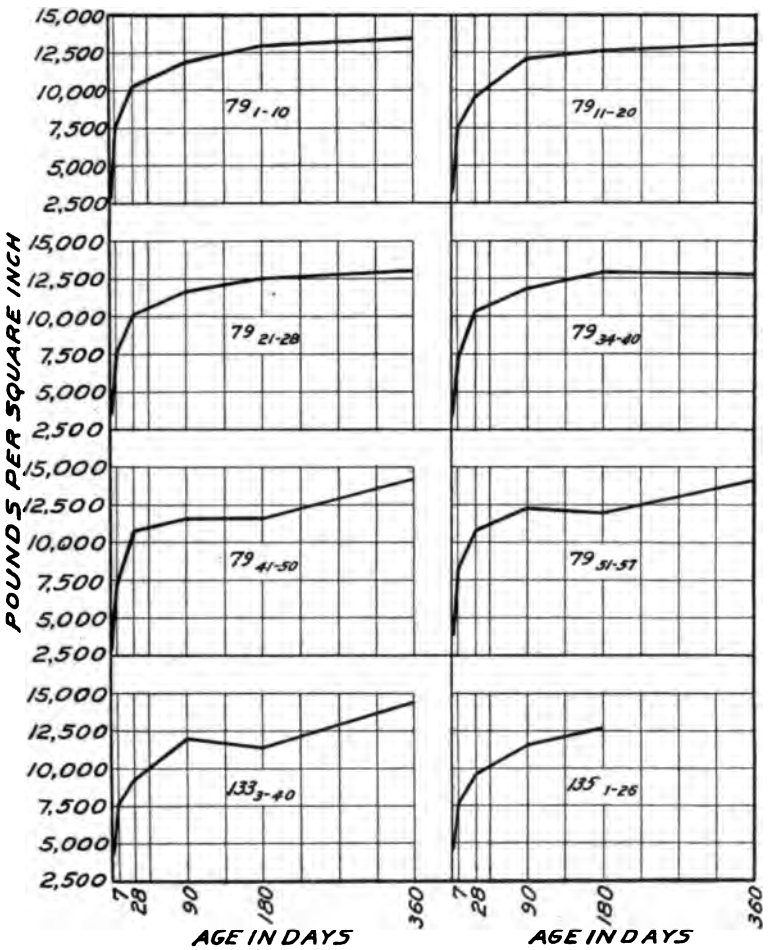


FIG. 7.—Curves showing variation of compressive strength with age of typical Portland cement.

curves seem to indicate that the strength increases to 90 days, remains practically constant to 180 days, and then decreases slightly to 360 days. When the first transverse test pieces were made the cement had been stored about a year, and a period of about five months had elapsed between the molding of the first and the last test pieces.

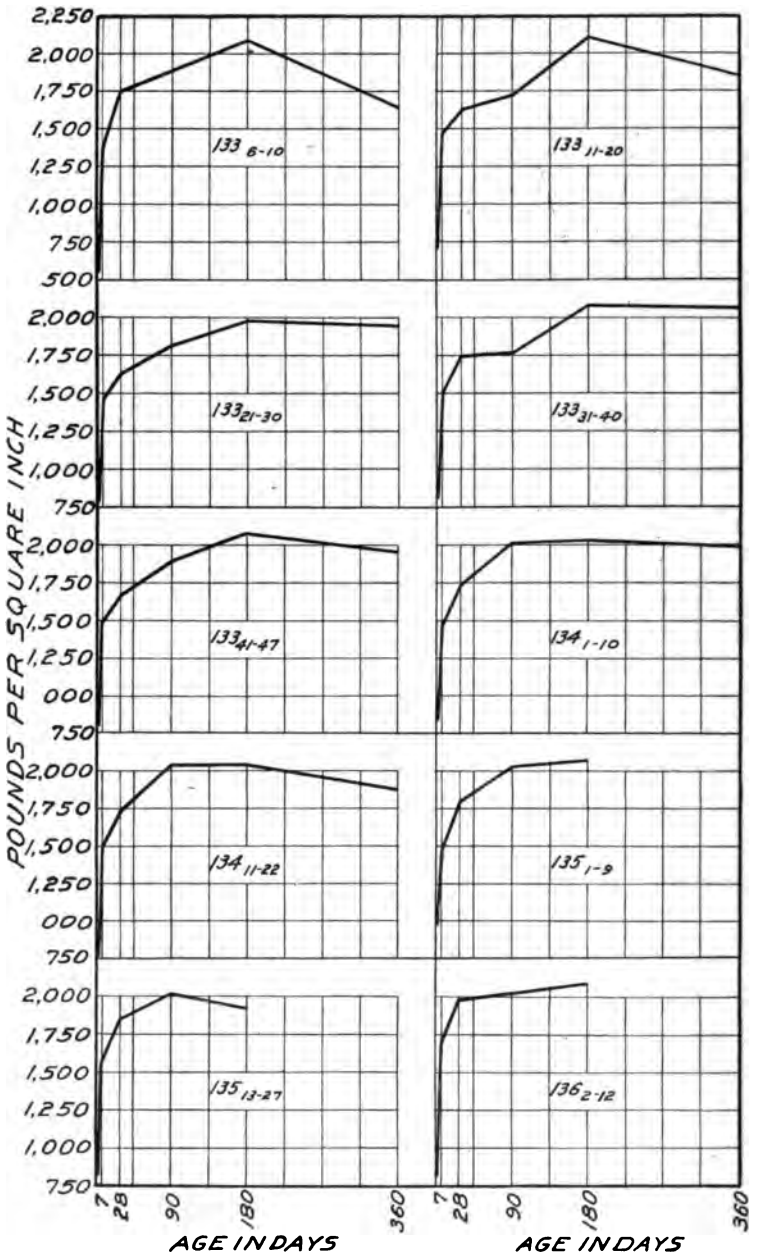
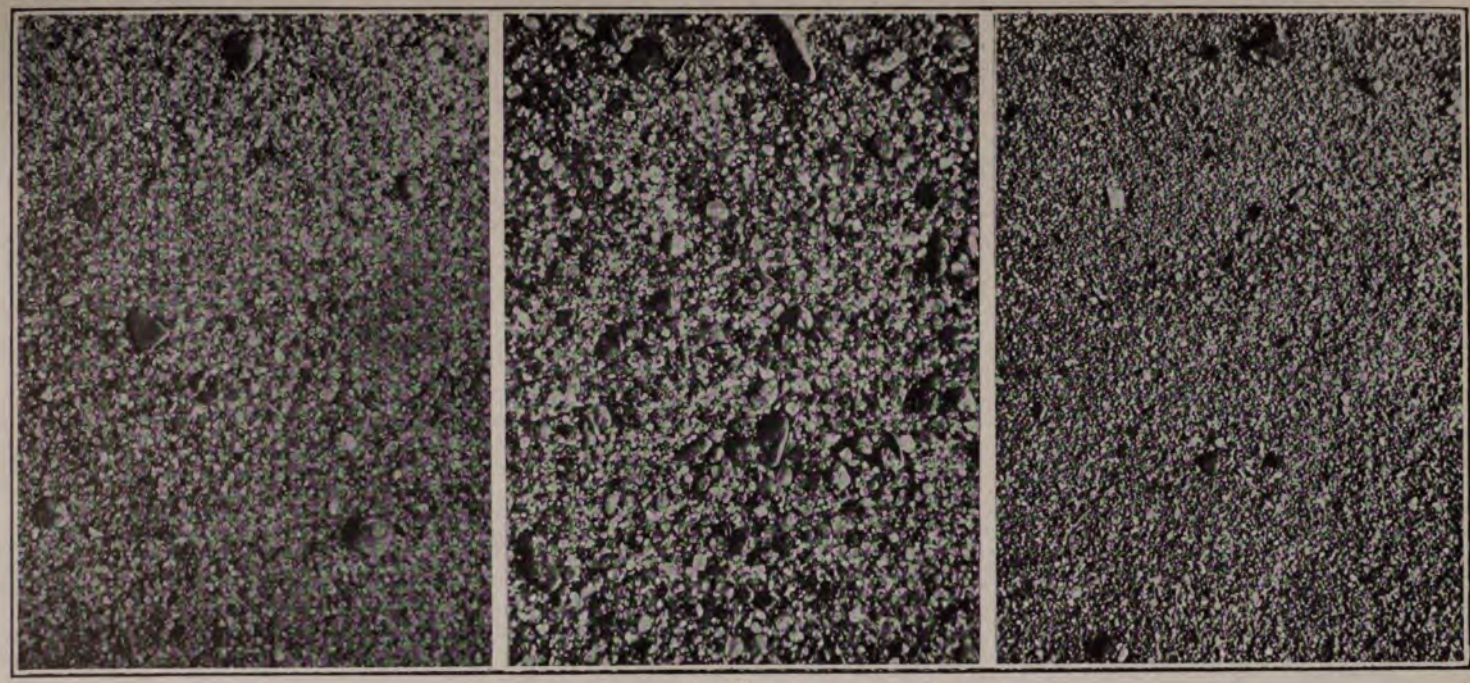


FIG. 8.—Curves showing variation of transverse strength with age of typical Portland cement.



A *B* *C*

A. MISSOURI RIVER SAND, KANSAS CITY, MO. (SAMPLE 1).
B. KAW RIVER SAND, ARMOURDALE, KANS. (SAMPLE 2).
C. SCIOTO RIVER SAND, COLUMBUS, OHIO (SAMPLE 3).

TABLE VIIc.—*Transverse strength of typical Portland cement used in mortar tests.*

Register No.	Temperature (° F.).		Water (per cent).	Transverse strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
133-6	71.6	64.2	20.5	540	1,332	1,782	1,836	2,160	1,566
133-7	69.8	64.2	20.5	540	1,368	1,800	2,070	2,124	1,530
133-8	69.8	65.4	20.5	630	1,386	1,602	1,908	1,890	1,338
133-9	69.8	68.0	20.5	774	1,422	1,764	1,746	2,088	1,620
133-11	63.0	70.7	20.5	738	1,332	1,728	1,512	2,160	1,944
133-12	63.0	67.1	20.5	792	1,548	1.494	1,512	2,106	1,908
133-13	63.5	74.0	20.5	738	1,386	1,440	1,872	2,016	1,962
133-14	66.2	78.8	20.5	792	1,512	1,692	1,710	2,106	1,944
133-15	68.0	78.8	20.5	756	1,602	1,746	1,818	2,142	1,890
133-16	67.1	68.0	20.5	756	1,620	1,386	1,908	2,070	1,926
Average	67.2	69.9	20.5	705	1,451	1,638	1,780	2,086	1,763
133-18	68.9	67.1	20.5	882	1,422	1,710	1,440	2,070	1,656
133-19	68.9	77.0	20.5	738	1,332	1,638	1,818	2,142	1,764
133-20	69.8	78.8	20.5	1,026	1,440	1,764	1,872	2,106	1,620
133-22	69.8	73.4	20.5	882	1,512	1,602	1,710	2,070	1,638
133-24	69.8	64.0	20.5	810	1,566	1,908	1,854	1,764	1,890
133-25	68.0	68.7	20.5	828	1,440	1,710	1,782	1,584	1,908
133-26	68.9	68.0	20.5	828	1,386	1,440	1,962	2,106	2,016
133-27	68.0	66.2	20.5	846	1,476	1,530	1,854	2,124	2,106
133-29	68.9	74.3	20.5	1,008	1,584	1,512	1,764	2,052	2,034
133-30	69.8	69.8	20.5	972	1,188	1,674	1,710	2,106	2,034
Average	69.1	70.7	20.5	882	1,435	1,650	1,777	2,012	1,867
133-31	68.0	77.0	20.5	792	1,566	1,836	1,764	2,070	2,088
133-32	71.6	80.6	20.5	972	1,494	1,710	1,638	.....	2,016
133-34	69.8	71.6	20.5	918	1,386	1,764	1,962	2,124	2,088
133-35	71.6	68.0	20.5	900	1,530	1,458	1,692	2,214	2,088
133-36	70.7	64.4	20.5	918	1,584	1,890	1,692	2,106	2,111
133-37	69.8	64.2	20.5	774	1,404	1,440	1,854	1,998	2,021
132-38	68.9	65.3	20.5	828	1,458	1,926	1,926	2,106	1,993
133-39	71.6	71.6	20.5	972	1,548	1,836	1,656	1,962	1,967
133-41	71.6	69.8	20.5	954	1,710	1,818	1,962	1,998	1,661
133-42	69.8	68.9	20.5	846	1,386	1,548	1,800	2,106	2,070
Average	70.3	70.1	20.5	889	1,498	1,724	1,795	2,076	2,010
133-43	70.7	71.6	20.5	864	1,368	1,746	1,836	2,160	2,070
133-44	70.7	74.3	20.5	864	1,458	1,692	1,836	2,214	1,818
133-47	70.7	77.0	20.5	846	1,404	1,602	1,980	2,178	1,944
134-1	72.4	78.8	20.5	828	1,494	1,638	1,854	1,962	1,980
134-2	77.0	78.8	20.5	972	1,440	1,440	1,944	2,160	2,025
134-3	74.3	80.0	20.5	810	1,656	1,674	1,944	2,106	1,926
134-4	76.1	74.8	20.5	954	1,278	1,890	2,124	2,124	1,944
134-5	75.2	72.5	20.5	918	1,548	1,728	2,142	1,908	1,957
134-6	75.2	70.7	20.5	846	1,422	1,746	1,962	1,854	1,920
134-8	76.1	77.0	20.5	936	1,476	1,782	2,016	2,016	2,052
Average	73.8	75.5	20.5	884	1,454	1,695	1,964	2,074	1,964
134-9	75.2	80.6	20.5	1,044	1,278	1,674	1,908	2,106	1,944
134-10	75.2	78.8	20.5	990	1,476	1,818	2,252	2,016	2,088
134-11	74.3	71.6	20.5	954	1,530	1,836	2,034	1,872	1,836
134-13	75.2	76.1	20.5	756	1,494	1,800	1,926	2,168	1,692
134-14	77.0	80.6	20.5	990	1,332	1,656	2,142	2,052	1,975
134-15	77.0	80.6	20.5	954	1,386	1,800	1,998	2,034	1,805
134-16	77.0	76.2	20.5	738	1,494	1,422	1,998	2,088	1,800
134-17	77.0	75.2	20.5	810	1,548	1,962	2,106	2,016	1,854
134-18	77.0	70.7	20.5	900	1,512	1,728	2,016	2,142	1,751
134-19	78.8	82.4	20.5	918	1,566	1,728	2,034	2,106	1,859
Average	76.4	77.1	20.5	905	1,461	1,742	2,041	2,060	1,865
134-20	75.2	73.4	20.5	1,008	1,530	1,890	2,034	1,962	2,147
134-21	77.0	77.0	20.5	414	1,674	1,584	2,016	2,034	2,003
134-22	78.8	73.4	20.5	900	1,566	1,746	2,088	1,962	1,823
135-1	78.8	82.4	20.5	1,008	1,620	1,854	2,052	1,962	1,908
135-3	78.8	80.6	20.5	1,008	1,242	1,854	2,016	2,088	2,003
135-4	78.8	82.4	20.5	1,296	1,476	1,602	2,016	2,106	.....
135-5	78.8	80.6	20.5	1,008	1,620	1,818	2,052	2,150	.....
135-6	79.5	77.0	20.5	990	1,476	1,674	2,016	2,124	.....
Average	77.2	78.4	20.5	954	1,823	1,753	2,036	2,047	1,977
135-7	78.8	78.8	20.5	936	1,476	1,602	2,070	2,034	.....
135-8	78.8	80.6	20.5	846	1,494	1,998	1,980	2,052	.....
135-13	80.6	80.6	20.5	918	1,440	1,638	2,052	1,926	.....
135-14	80.6	84.2	20.5	972	1,584	1,854	2,070	1,602	.....
135-15	80.6	82.4	20.5	774	1,584	1,782	2,034	1,872	.....

TABLE VIIc.—*Transverse strength of typical Portland cement used in mortar tests*—Con.

Register No.	Temperature (° F.).		Water (per cent).	Transverse strength (pounds per square inch).					
	Water.	Air.		1 day.	7 days.	28 days.	90 days.	180 days.	360 days.
135-16	81.4	82.4	20.5	918	1,656	1,818	1,980	1,818	.....
135-17	77.0	68.0	20.5	918	1,782	1,854	2,070	2,034	.....
135-19	77.0	68.0	20.5	810	1,656	1,962	2,070	2,052	.....
Average	79.3	76.9	20.5	886	1,584	1,814	2,041	1,926	.....
135-21	79.5	76.1	20.5	1,008	1,458	2,070	2,034	2,016	.....
135-22	78.8	75.2	20.5	990	1,170	1,962	1,980	1,980	.....
135-27	78.8	84.2	8.9	828	1,476	1,674	1,998	1,890	.....
136-2	80.6	82.4	20.5	576	1,692	1,908	2,088	2,052	.....
136-3	78.8	80.6	20.5	900	1,584	1,998	2,070	2,160	.....
136-4	77.9	76.1	20.5	972	1,314	1,980	2,034	2,142	.....
136-9	78.8	68.9	20.5	936	1,764	1,962	2,052	1,998	.....
136-11	77.0	68.0	20.5	1,116	1,746	2,034	2,124	2,142	.....
136-12	76.1	71.6	20.5	954	1,854	1,962	2,016	2,070	.....
Average	77.3	75.9	20.5	920	1,562	1,950	2,046	2,050	.....

Lapse of time between first and last molding.—The tension- and compression-test pieces of typical Portland cement were made at about the same time, the first mix being exhausted before the transverse molds arrived at the laboratories. While the transverse-test pieces were being made, the second, third, and fourth mixes were used, and part of these, as well as a portion of the fifth mixture, were used in molding the transverse-test pieces. As far as can be seen from the results, there was no appreciable difference in the qualities of the cements in the different mixtures.

SANDS AND SAND MORTARS.

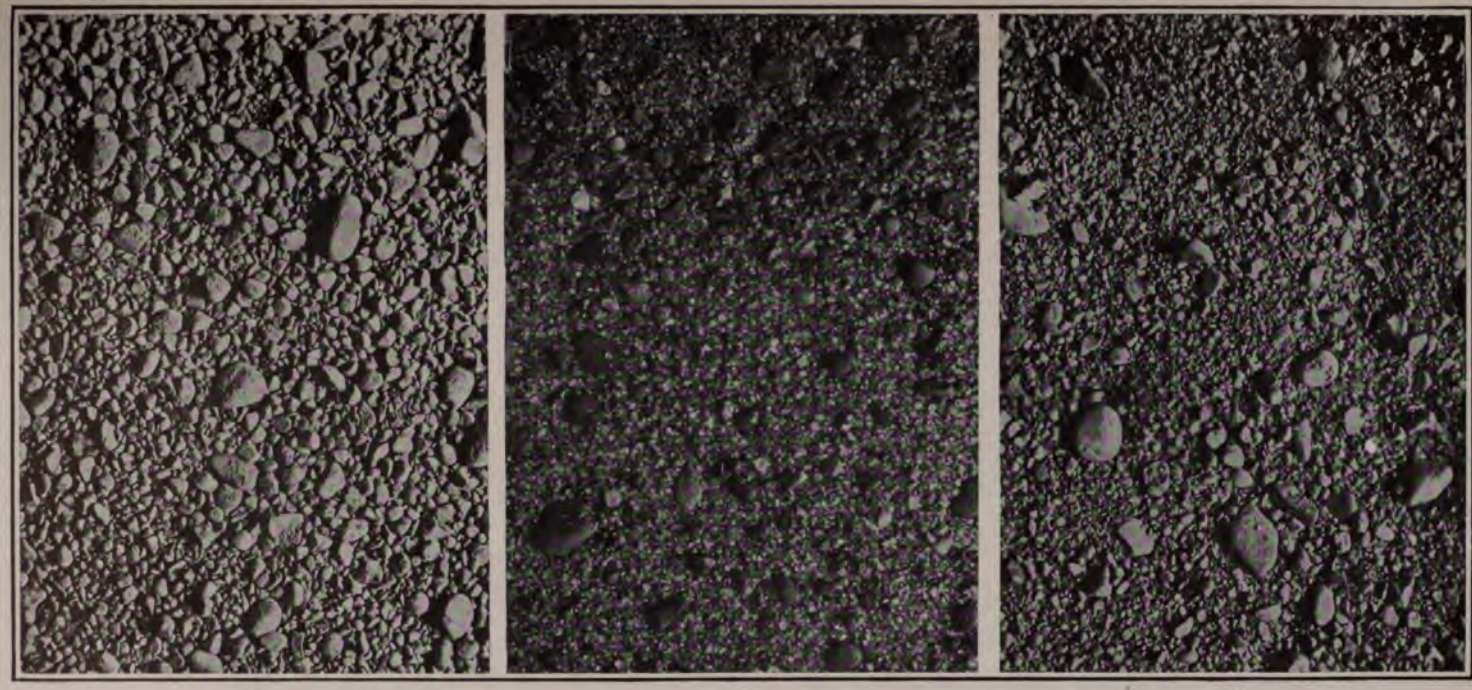
ACKNOWLEDGMENT OF DONATIONS.

In the investigations reported in this bulletin 22 sands were used. They were generously donated by the following firms and companies :

American Sand and Gravel Company, Chicago, Ill.
Buckeye Dredging Company, Columbus, Ohio.
William P. Carmichael, Attica, Ind.
Fleming & Co., Cincinnati, Ohio.
C. H. Little & Co., Detroit, Mich.
Miami Sand and Gravel Company, Loveland, Ohio.
Mound City Gravel and Cement Company, Moselle, Mo.
Ohio and Michigan Gravel and Sand Company, Chilson, Mich.
Stewart Peck Sand Company, Kansas City, Mo.
Toledo Stone and Glass Sand Company, Toledo, Ohio.
Union Sand and Material Company, St. Louis, Mo.
R. J. Ware & Sons, Cincinnati, Ohio.

METHOD OF COLLECTION.

In almost every case, in order to insure the collection of a typical sample of any sand, a special representative of the laboratories visited the deposit and personally supervised its collection and shipment.



A *B* *C*

A. BANK SAND, SYMMES, OHIO (SAMPLE 4).
B. OHIO RIVER SAND, CINCINNATI, OHIO (SAMPLE 5).
C. BANK SAND, ST. CHARLES, ILL. (SAMPLE 6).

Samples were shipped in double sacks, the inner of which was a close-textured grain bag, and the outer a coarse bag of burlap. This precaution was taken in order to eliminate as far as possible the possibility of losing any part of the fine material. A complete description of each sample of sand is given in the following pages; also illustrations from photographs. All the sands were subjected to the usual physical tests and were mixed with typical Portland cement to make mortar test pieces.

DESCRIPTIONS OF SANDS.

Register No. Sd. 1.—A recent river sand, designated Sd. 1, was pumped from the Missouri River channel at Kansas City, Mo., and discharged upon scows, in which it was transported to Kansas City. An endeavor was made to procure the sand in its original condition, so as to determine the proportion of silt and its consequent effect on mortars in which the sand was used; but this was found practically impossible, as a large amount of the silt was washed away in pumping, and when received at the laboratories the determination showed only 0.2 per cent of silt. While this does not indicate the amount of silt present in the original sand, it does show the condition of the sand marketed. It is reported to be used for all purposes except that it is unsuited for finishing work because of a tendency to check or peel off.

An examination of the granularmetric analysis curve (fig. 10, p. 48) proves this material to be one of the "finest" sands received at the laboratories. The physical properties of this and other sands and screenings are shown in Table VIII (p. 59). The percentage of voids is 32.5; the weight per cubic foot is 109.3 pounds; and the yield in 1:3 mortar is 1.18. The results of the strength tests of mortars made by the use of one part of typical Portland cement to 3 parts, to 4 parts, and to 3 parts sifted to 30–40 size of this and 21 other sands are given in Table IX (p. 62). Pl. I, *A*, illustrates this sand, showing the material in its actual size, great care having been taken to procure a photograph that would represent as nearly as possible the grading and the relative proportion of fine and coarse material.

Register No. Sd. 2.—Another recent river sand, designated Sd. 2, was obtained from the channel of Kansas (Kaw) River, at Armourdale (a part of Kansas City, Kans.), by means of a dredge and pump, and discharged into a scow.

The granularmetric analysis curve (fig. 11, p. 50) indicates that about 70 per cent passes the No. 20 sieve and about 15 per cent passes the No. 40 sieve. The percentage of voids is 34.9; the weight per cubic foot is 107.7 pounds; there is only a trace of silt, and the yield

in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). This sand is illustrated in Pl. I, *B*.

Register No. Sd. 3.—A river sand designated Sd. 3 was obtained from Scioto River at Columbus, Ohio, by means of an endless-chain device with elevator buckets. The material was dumped upon scows and transferred to cars by means of a traveling crane.

The granularmetric analysis curve is shown in fig. 12 (p. 52), and the appearance in Pl. I, *C*. The percentage of voids is 36.1; the weight per cubic foot is 103.3 pounds; the amount of silt is 4.2 per cent, and the yield in 1:3 mortar is 1.09. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 4.—Sand designated Sd. 4 was obtained from a gravel bank of glacial origin located at Symmes, Ohio. The material, consisting of sand, gravel, and bowlders, was excavated from a bank about 600 feet long by means of a steam shovel. After excavation it was passed through a crusher, following which it was screened and washed.

An inspection of the granularmetric analysis curve (fig. 13, p. 54), indicates that this is next to the coarsest and most uniformly graded of the 22 sands herein described. Only 32 per cent passed the No. 20 sieve. The appearance is shown in Pl. II, *A*. The percentage of voids is 28; the weight per cubic foot is 116.4 pounds; the amount of silt is 1.4 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 5.—A river sand designated Sd. 5 consisted of a mixture of sand and gravel excavated from the Ohio River shore near Cincinnati by means of a centrifugal pump. The material was discharged into barges, from which it was loaded into wagons for distribution throughout the city. The bank that was worked extended for a distance of 500 feet along the Ohio River shore. After being taken from the river the sand was passed through a ¼-inch screen and washed.

The grading of this sand is somewhat irregular, as shown by the granularmetric analysis curve in fig. 11 (p. 50) and the appearance in Pl. II, *B*. The percentage of voids is 34.6; the weight per cubic foot is 104.8 pounds; a trace only of silt is present, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 6.—The sample designated Sd. 6 is a bank sand, a glacial deposit near Fox River, and was excavated by tram and bucket from the sand pit at St. Charles, Ill.

As shown by the granularmetric analysis curve (fig. 11, p. 50), this sand is rather fine, 68 per cent passing the No. 20 sieve. The

A *B* *C*

A. BANK SAND, FOX RIVER, CARPENTERVILLE, ILL. (SAMPLE 7).
B. BANK SAND, FOX RIVER, ALGONQUIN, ILL. (SAMPLE 8).
C. BANK SAND, DESPLAINES RIVER, LIBERTYVILLE, ILL. (SAMPLE 9).

percentage of voids is 31.6; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.53 per cent; and the yield in 1:3 mortar is 1.14. The results of tests of mortars made from this sand are given in Table IX (p. 62) and the appearance is shown in Pl. II, *C*.

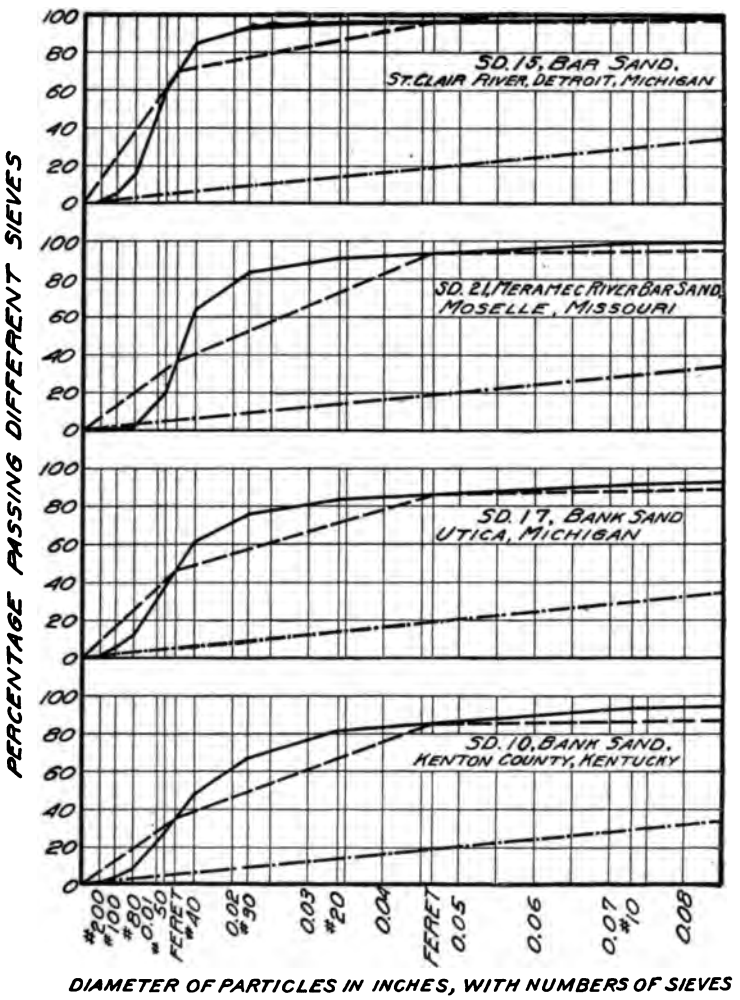


FIG. 9.—Granularmetric analysis curves for sands 15, 21, 17, and 10. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Register No. Sd. 7.—The sample designated Sd. 7 was obtained by means of a tram and bucket from a glacial deposit of indefinite extent along Fox River at Carpenterville, Ill.

As indicated by the granularmetric analysis curve (fig. 10, p. 48) and the appearance (Pl. III, *A*), this sand contains a large amount

of fine material, 77 per cent passing the No. 20 sieve. The percentage of voids is 31.6; the weight per cubic foot is 116 pounds; the amount of silt is 1.2 per cent; and the yield in 1:3 mortar is 1.22. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 8.—Material designated Sd. 8 is bank sand from a portion of a glacial deposit along Fox River in the vicinity of Algonquin, Ill., and was excavated by means of tram and bucket.

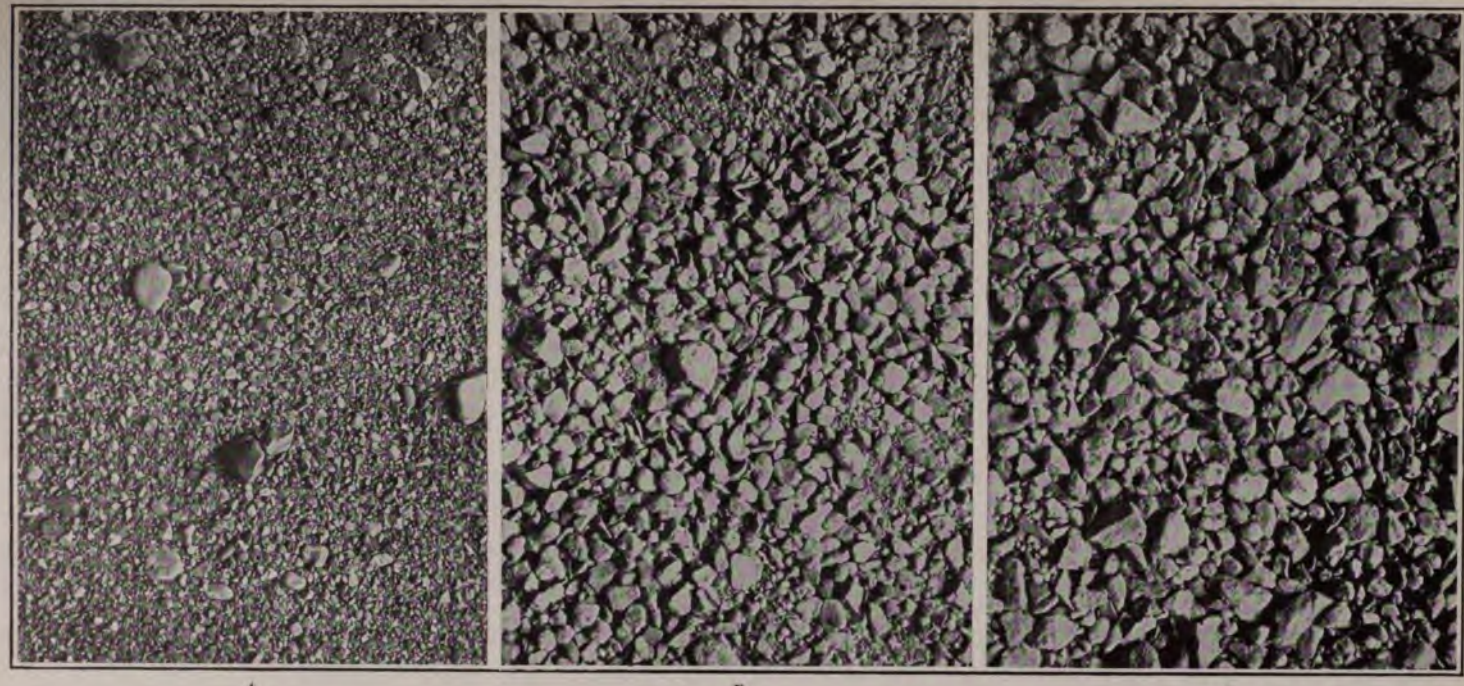
As shown by the granularmetric analysis curve (fig. 13, p. 54) this sand is somewhat coarser than the average, but it is very uniformly graded, and only 46 per cent passed the No. 20 sieve. The percentage of voids is 30.7; the weight per cubic foot is 114.5 pounds; the amount of silt is 1.3 per cent; and the yield in 1:3 mortar is 1.16. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). This sand is illustrated in Pl. III, *B*. The presence of particles from the smallest up to the ¼-inch size indicates to the eye the uniform grading.

Register No. Sd. 9.—The sample designated Sd. 9 was taken by means of a dredge from a glacial deposit along Desplaines River at Libertyville, Ill.

As indicated by the granularmetric analysis curve for this sand (fig. 12, p. 52), it is very uniformly graded, and only about 50 per cent passes the No. 20 sieve. The percentage of voids is 31.4; the weight per cubic foot is 110.5 pounds; the amount of silt is 2.6 per cent; and the yield in 1:3 mortar is 1.16. The particles of this sand are so soft that they can easily be crushed between the fingers. The uniform grading of this sand indicates that the strength of the mortar should be high; but, evidently owing to the character of the sand, this expectation was not borne out in the tests. This sand is illustrated in Pl. III, *C*. The uniform grading is clearly apparent. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 10.—The sample designated Sd. 10 is a mixture of outwash glacial and alluvial deposits from a bank located in Kenton County, Ky. The working was about 600 feet long by 70 feet wide, and the sand was shipped to the vicinity of Cincinnati, Ohio. The face of the bank ahead of the work had a peculiar appearance, on account of the arrangement of the strata. The layer of sand that was excavated was covered by a 4-foot layer of moldy sand and a 10-foot layer of gravel.

As indicated by the granularmetric analysis curve (fig. 9, p. 45), this sand contains a large amount of fine material, 9 per cent passing the No. 80 sieve and about 82 per cent passing the No. 20 sieve. The percentage of voids is 31.6; the weight per cubic foot is 110 pounds; the amount of silt is 2.1 per cent; and the yield in 1:3 mortar is 1.18.



A *B* *C*

A. BANK SAND, KENTON COUNTY, KY. (SAMPLE 10).
B. MIXED LIMESTONE SCREENINGS AND SAND, TOLEDO, OHIO (SAMPLE 11).
C. MIXED LIMESTONE SCREENINGS AND SAND, TOLEDO, OHIO (SAMPLE 12).

In the illustration of this sand (Pl. IV, *A*) the small amount of large material and the large amount of smaller particles present can be clearly seen. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).

Register No. Sd. 11.—Material designated Sd. 11 is a mixture of washed magnesian limestone crusher screenings and a washed glass sand. The limestone is from the Monroe formation (Silurian) and was removed by the open-face method, dynamite being used for blasting and compressed air for drilling. The sand (Sylvania sandstone) is found between two limestone beds in the quarry. The working face is about 2,500 feet long and about 30 feet high. This quarry was operated by an elaborate gravity system. The material was marketed in Detroit, Mich., and in Toledo and Cleveland, Ohio, in three grades, viz, coarse, medium, and fine, sand 11 being the medium grade.

According to the granularmetric analysis curve (fig. 12, p. 52), this mixture of sand and limestone is shown to be very uniformly graded, and 46 per cent passes the No. 20 sieve. The sample is illustrated in Pl. IV, *B*. The amount of voids is 36 per cent; the weight per cubic foot is 110 pounds; the amount of silt is 3.4 per cent; and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 12.—The sample designated Sd. 12 is the finest grade prepared in the manner described for Sd. 11.

As shown by the granularmetric analysis curve (fig. 13, p. 54) and the illustration from photograph (Pl. IV, *C*), this sand is very uniformly graded; and 41 per cent passes the No. 20 sieve. The percentage of voids is 35.5; the weight per cubic foot is 106.5 pounds; the amount of silt is 4.7 per cent; and the yield in 1:3 mortar is 1.12, which is practically the same as that of Sd. 11. The results of the strength tests of mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 13.—The sample designated Sd. 13 is a washed sand of glacial origin, containing particles up to one-eighth inch in diameter. It was excavated by means of a steam shovel from a bank 5,000 feet long and 300 feet wide at Chilson, Mich., and was being shipped to Toledo, Ohio.

As indicated by the granularmetric analysis curve (fig. 13, p. 54), this is one of the most uniformly graded sands used in these investigations; and 38 per cent passes the No. 20 sieve. The appearance is shown in Pl. V, *A*. The percentage of voids is 28.9; the weight per cubic foot is 119.5 pounds; the amount of silt is 0.3 per cent; and the yield in 1:3 mortar is 1.21. The results of the tests on mortars made from this mixture are given in Table IX (p. 62).

Register No. Sd. 14.—The sample designated Sd. 14 was removed from the north channel of St. Clair River by means of a centrifugal

pump, after which it was screened and loaded in scows for delivery to Detroit.

As indicated by the granularmetric analysis curve (fig. 10) and the illustration from a photograph (Pl. V, B), this sand has a large amount of small grains, 71 per cent passing the No. 20 sieve.

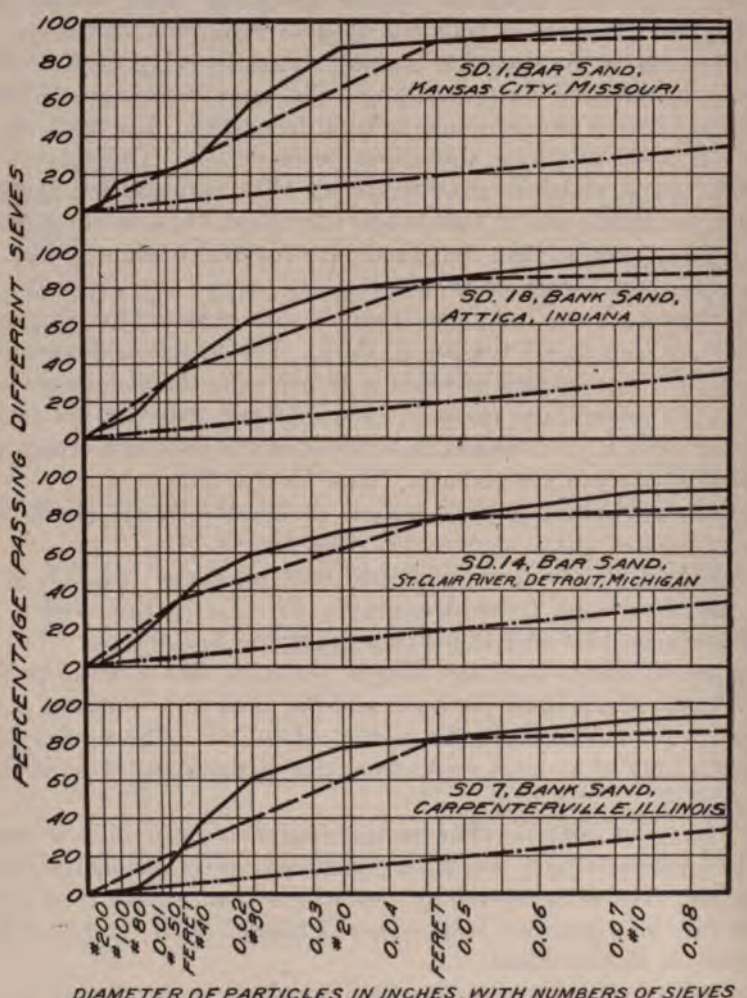
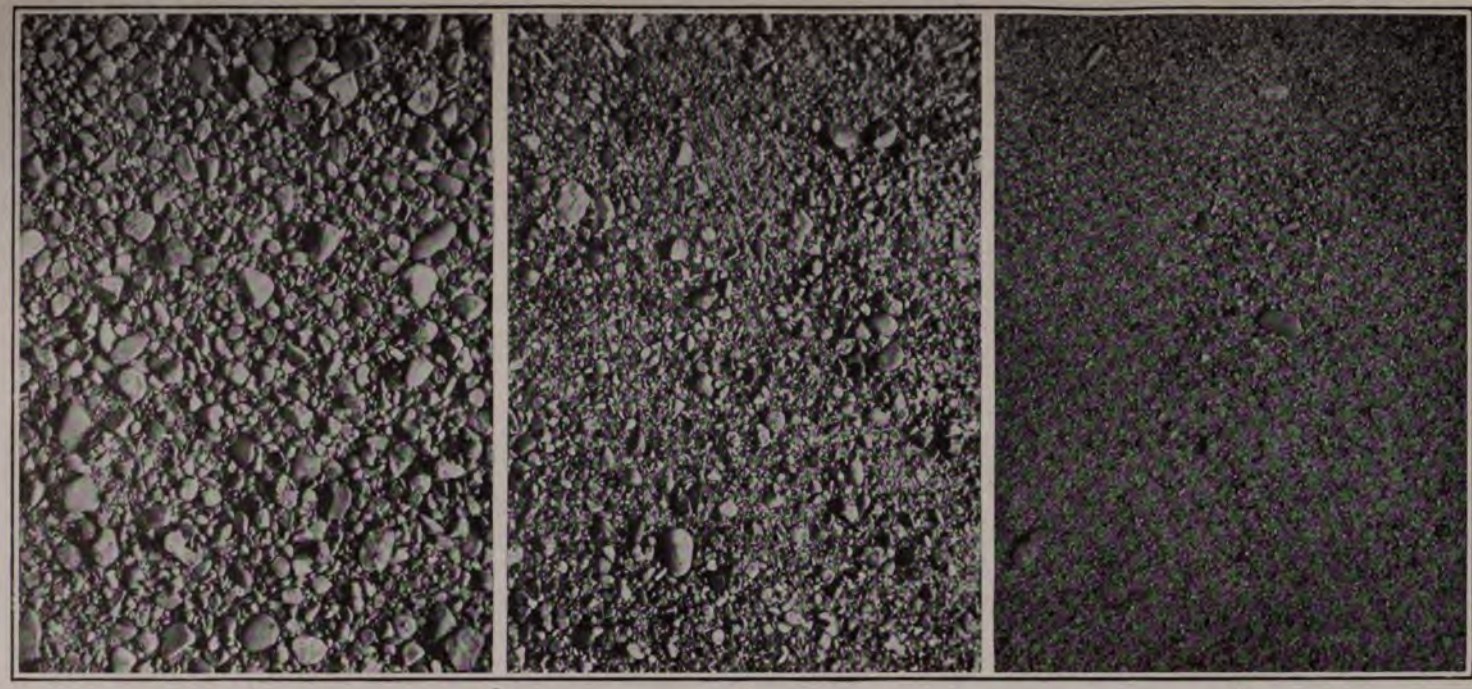


FIG. 10.—Granularmetric analysis curves for sands 1, 18, 14, and 7. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

The percentage of voids is 31.9; the weight per cubic foot is 111 pounds; the amount of silt is 2 per cent; and the yield in 1:3 mortar is 1.19. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62).



A *B* *C*

A. BANK SAND, CHILSON, MICH. (SAMPLE 13).
B. ST. CLAIR RIVER SAND, DETROIT, MICH. (SAMPLE 14).
C. ST. CLAIR RIVER SAND, DETROIT, MICH. (SAMPLE 15).

Register No. Sd. 15.—The sample designated Sd. 15 is a very fine sand, extensively used as a finishing sand for sidewalks and concrete blocks. It was taken from St. Clair River by means of a centrifugal pump, loaded in scows and transported to Detroit.

According to the granularmetric analysis curve (fig. 9, p. 45) this sand is the finest of the 22 sands herein described, 96 per cent passing the No. 20 sieve and 85 per cent passing the No. 40 sieve. The percentage of voids is 40.5; the weight per cubic foot is 95 pounds; the amount of silt is 2 per cent, and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). Pl. V, *C* shows that there is only an occasional large particle in the sand, the great mass of the particles being exceedingly small.

Register No. Sd. 16.—The sample designated Sd. 16 was obtained at the beach of St. Clair River near Amherstburg, Ontario, by means of a centrifugal pump, and was dumped into scows and towed to Detroit.

The granularmetric analysis curve of this sand is shown in fig. 13 (p. 54). The percentage of voids is 29.7; the weight per cubic foot is 119.5 pounds; the amount of silt is 0.2 per cent, and the yield in 1:3 mortar is 1.20. The results of the strength tests of mortars made from this sand are given in Table IX (p. 62). The illustration of this sand (Pl. VI, *A*) shows that the material is very uniformly graded, particles of almost all sizes being in sight.

Register No. Sd. 17.—The sample designated Sd. 17 was excavated by pick and shovel from a rather dirty bank of glacial material, at Utica, Mich., and shipped to Detroit.

According to the granularmetric analysis curve (fig. 9, p. 45) this is a very fine sand, 61 per cent passing the No. 40 sieve and 83 per cent passing the No. 20 sieve. The percentage of voids is 34.5; the weight per cubic foot is 105.5 pounds; the amount of silt is 3.4 per cent, and the yield in 1:3 mortar is 1.27. The results of the strength tests on mortars made from this sand are given in Table IX (p. 62). The appearance of the sand is shown in Pl. VI, *B*.

Register No. Sd. 18.—The sample designated Sd. 18 was screened from a gravel of glacial origin at Attica, Ind. It was excavated from the bank by a steam shovel, and was then screened into several sizes and washed.

According to the granularmetric analysis curve (fig. 10) this sand is rather fine, 79 per cent passing the No. 20 sieve, 44 per cent passing the No. 40 sieve, and 14 per cent passing the No. 80 sieve. Its appearance is shown in Pl. VI, *C*. The percentage of voids is 34; the weight per cubic foot is 106.5 pounds; the amount of silt present is 3.9 per cent, and the yield in 1:3 mortar is 1.15. The

results of the strength tests of mortars made from this sand are shown in Table IX (p. 62).

Register No. Sd. 19.—A second sample, screened from the same deposit at Attica, Ind., was designated Sd. 19.

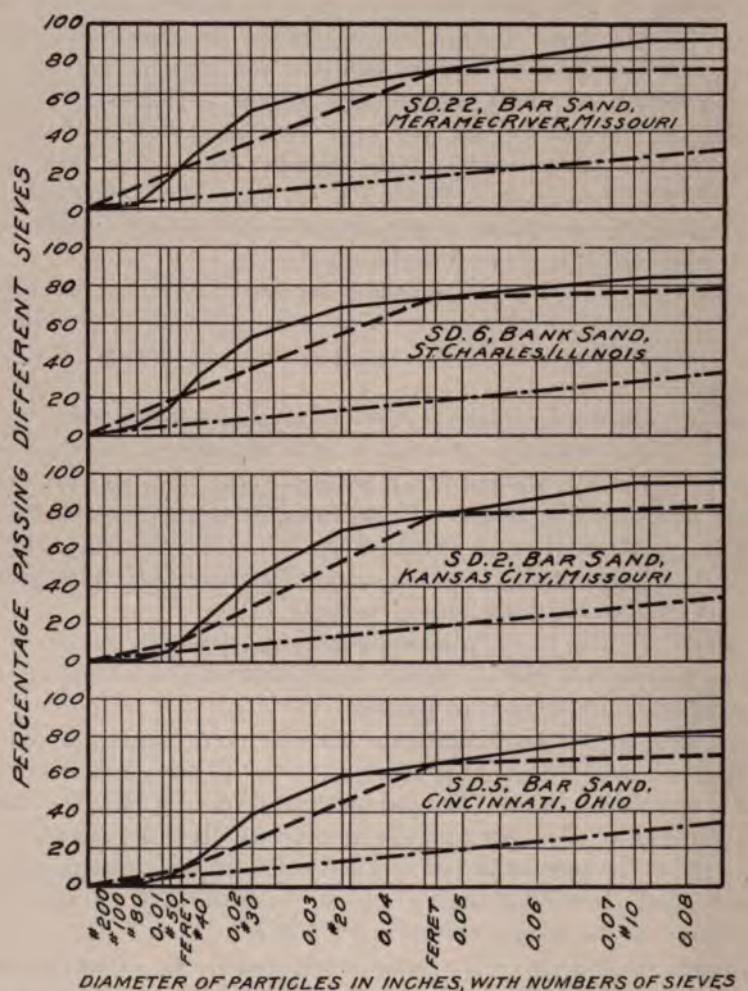
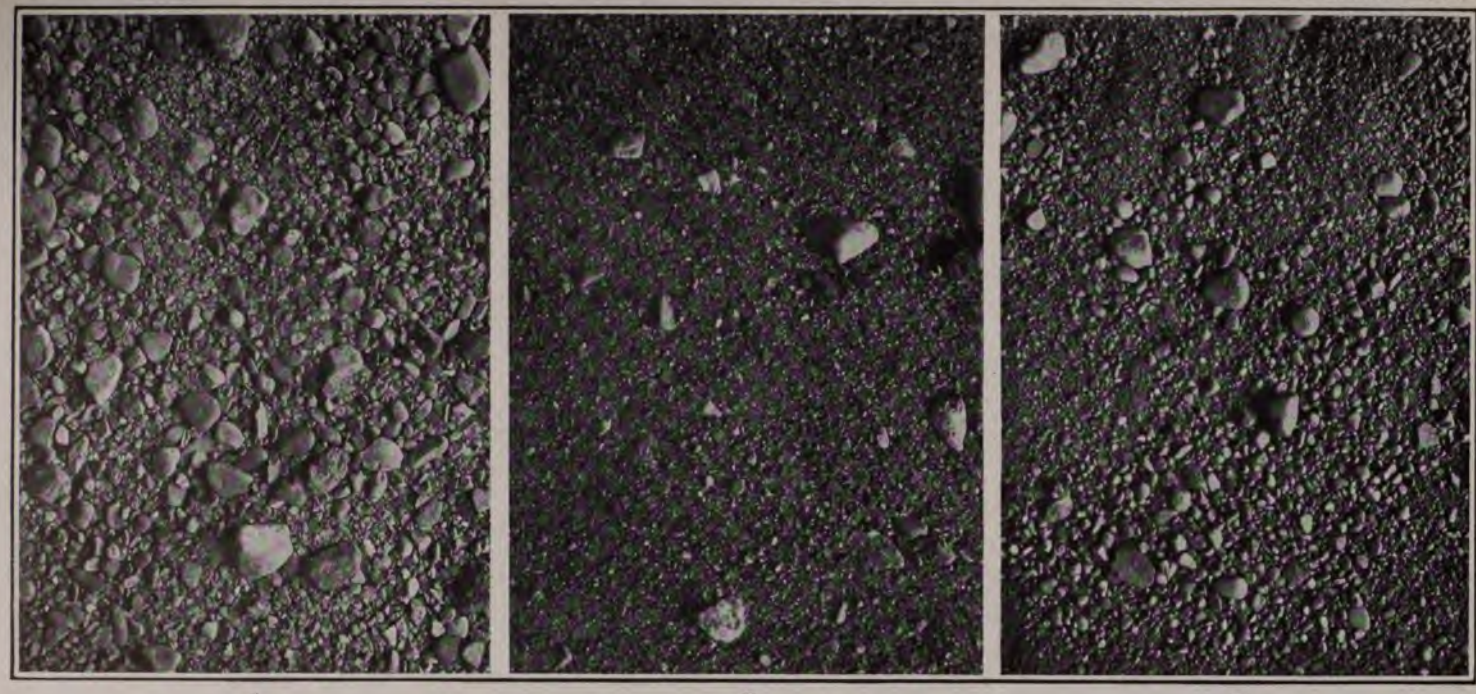


FIG. 11.—Granularmetric analysis curves for sands 22, 6, 2, and 5. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

According to the granularmetric analysis curve (fig. 12, p. 52) this material is very uniformly graded; 45 per cent passes the No. 20 sieve, 29 per cent passes the No. 30 sieve, and 2 per cent passes the No. 80 sieve. The percentage of voids is 26.9, the weight per cubic foot is 119.9 pounds, the amount of silt is 0.7 per cent, and the yield



A *B* *C*

A. ST. CLAIR RIVER SAND, AMHERSTBURG, ONTARIO (SAMPLE 16).
B. BANK SAND, UTICA, MICH. (SAMPLE 17).
C. BANK SAND, ATTICA, IND. (SAMPLE 18).

in 1:3 mortar is 1.19. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62). This sand is illustrated in Pl. VII, *A*. The comparatively unifórm grading is evident, and it can be seen that the sizes range uniformly from the largest down to the smallest.

Register No. Sd. 20.—A third sample, from the same bank as Sd. 18 and Sd. 19, was designated Sd. 20.

According to the granularmetric analysis curve (fig. 12, p. 52) this sand is midway between a fine and a uniformly coarse sand, 50 per cent passing the No. 20 sieve. The percentage of void is 28; the weight per cubic foot is 116.5 pounds; the amount of silt is 1.3 per cent, and the yield in 1:3 mortar is 1.16. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62), and the sand is illustrated in Pl. VII, *B*.

Register No. Sd. 21.—The sample designated Sd. 21 is a bar sand from Meramec River at Moselle, Mo.

According to the granularmetric analysis curve (fig. 9, p. 45) this is a very fine sand, 82 per cent passing the No. 30 sieve and 2 per cent passing the No. 80 sieve. A large amount of this sand, over 60 per cent, is of approximately one size, between Nos. 30 and 50 sieves. This may be seen in the photograph reproduced in Pl. VII, *C*. The percentage of voids is 40.9; the weight per cubic foot is 89 pounds; a trace only of silt is present, and the yield in 1:3 mortar is 1.05. The results of the strength tests of mortars made from this sand are shown in Table IX (p. 62).

Register No. Sd. 22.—A sand generously donated in large quantities by a St. Louis company is used at the laboratories wherever a standard sand is required in tests not involving the quality of the cement. The selection was influenced (1) by the physical quality of the sand and (2) by the facility with which it could be procured. It is designated Sd. 22 and is a recent river sand, pumped by a suction dredge from the bed of Meramec River at Drake, Mo., about 15 miles from the laboratories. The dredge deposits the material in scows which convey it a few hundred yards to the screens where it is elevated by means of a clam-shell bucket and washed down through a series of screens, which separate the material into 2-inch, 1-inch, ½-inch, coarse, and fine sizes.

The granularmetric analysis curve (fig. 11, p. 50) indicates that it lies midway between the coarse and the fine sands, and that it is uniformly graded; 93 per cent passes the No. 10 sieve, 69 per cent passes the No. 20 sieve, 55 per cent passes the No. 30 sieve, and 17 per cent passes the No. 50 sieve. The percentage of voids is 36.4; the weight per cubic foot 98.8 pounds; there is only a trace of silt, and the yield in 1:3 mortar is 1.11. The results of the strength tests of

mortars made from this sand are shown in Table IX (p. 62). This sand is illustrated in Pl. VIII, *A*.

Standard Ottawa sand.—Sand from the St. Peter formation at Ottawa, Ill., sifted to 20–30 size, was designated standard Ottawa sand. That the grains are almost all of the same size can readily be

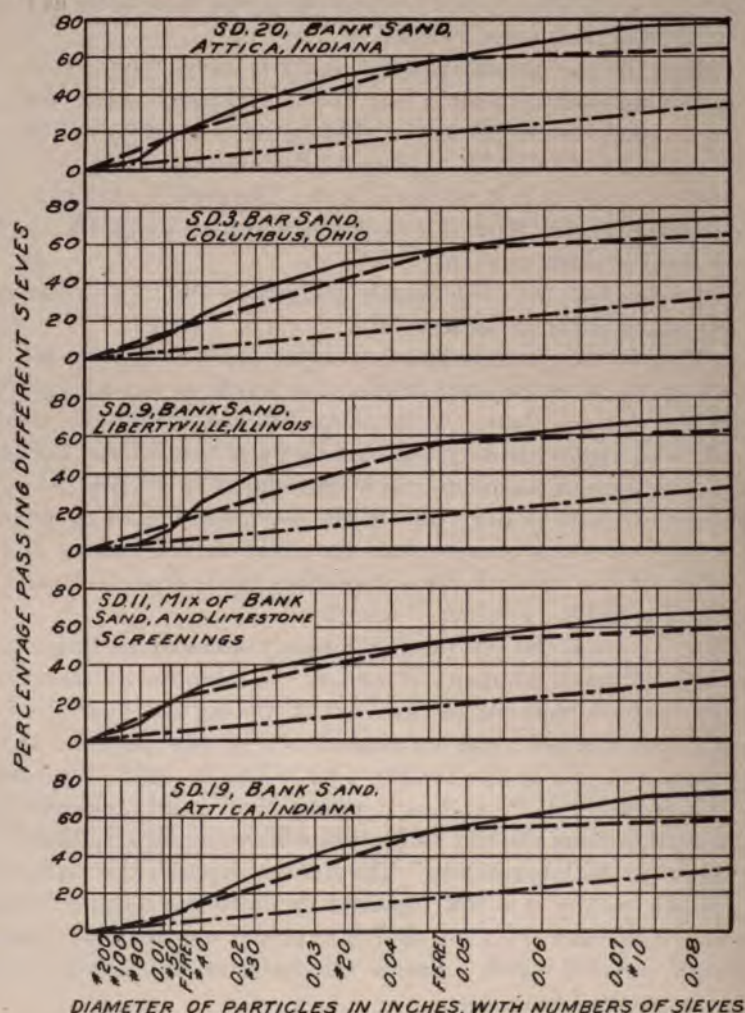
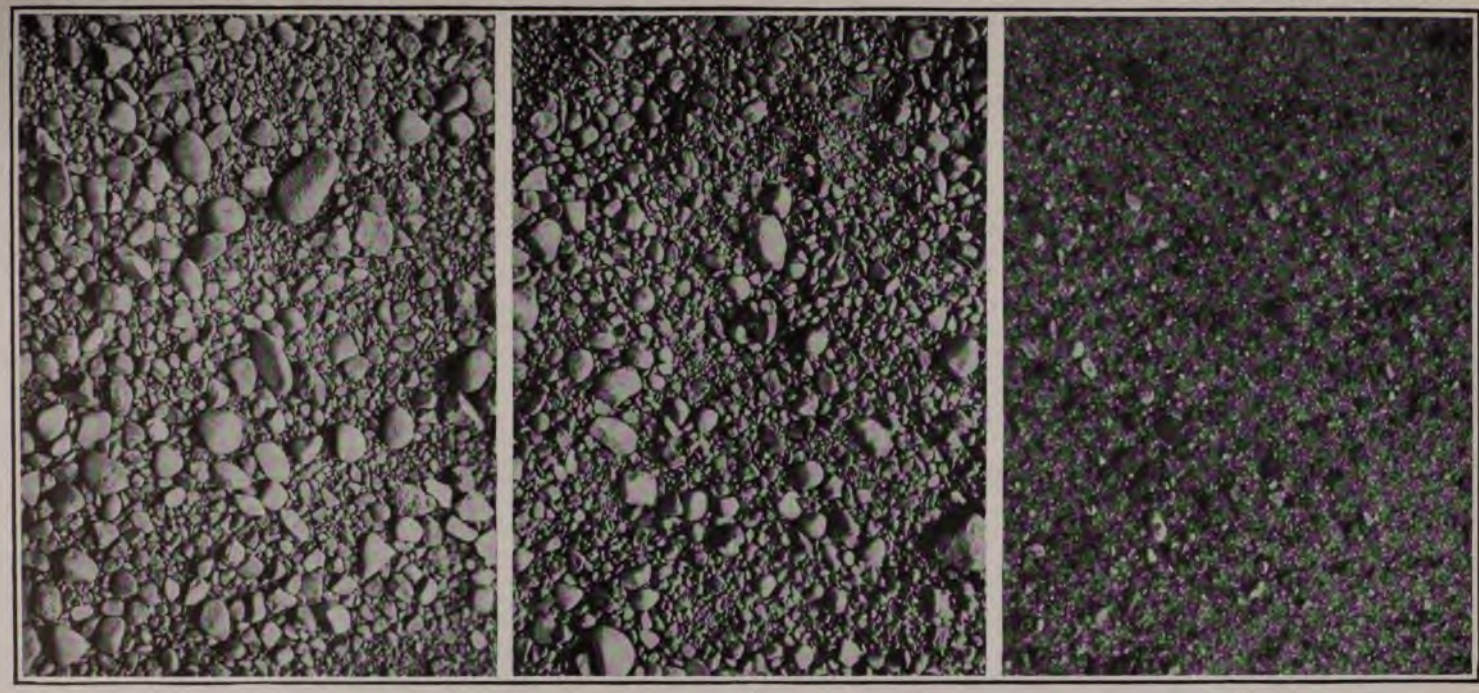


FIG. 12—Granularmetric analysis curves for sands 20, 3, 9, 11, and 19. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

seen by an inspection of Pl. VIII, *B*. This is a standard sand used in investigations of cement so as to give comparable results. The results of some tests of 1:3 mortar made from this sand are given in Tables II (p. 13), IV (p. 29), and VI (p. 32).



A *B* *C*

A. BANK SAND, ATTICA, IND. (SAMPLE 19).
B. BANK SAND, ATTICA, IND. (SAMPLE 20).
C. MERAMEC RIVER SAND, MOSELLE, MO. (SAMPLE 21).

PHYSICAL TESTS OF SANDS.

Method.—When a sample of sand is received at the laboratories it is spread on a concrete floor in a thin layer and turned at frequent intervals for a period varying from a few hours to 2 days, until it is thoroughly air dried. The temperature of the room in which the air drying takes place is maintained at about 70° F.

The sands (all of which have previously passed the ¼-inch screen) are submitted to tests for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, percentage of moisture, and the percentage and the chemical analysis of silt, which are determined and recorded as explained in Bulletin No. 329. The results of the chemical analyses of the silts are given in Table X (p. 77), and of the other determinations in Table VIII (p. 59).

Granularmetric analyses.—The set of sieves for the granularmetric analyses comprises those with 10, 20, 30, 40, 50, 80, 100, and 200 openings per linear inch. A sample of the air-dried material is placed on the upper of the nest of sieves and shaken for 15 minutes, when the residue on each sieve and the material passing the No. 200 sieve are weighed. The weight of material retained on each sieve and passing the No. 200 sieve is divided by the weight of the original sample to find the percentages retained on each sieve and passing the No. 200 sieve. These percentages are given in Table VIII (p. 59). Granularmetric analysis curves are also drawn for purposes of comparison.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 9–13, the ordinate at any sieve being the total percentage that passes that sieve, and not, as in Table VIII (p. 59) the percentage retained by the sieve. The percentage passing any sieve is found by adding together the percentages retained on all the smaller sieves and that passing the No. 200 sieve. At the left-hand side of each curve are given the percentages, and at the bottom of each figure the diameters of the particles that pass the different sieves, also the numbers of the standard sieves used in the work. Starting at the top of fig. 9 (p. 45) with the curve of the sand (Sd. 15) having the largest amount of fine material, these curves are arranged in consecutive order, ending at the bottom of fig. 13, with the curve of the sand (Sd. 16) having the largest amount of coarse material.

The granularmetric analysis curves, as determined by the standard sieves previously referred to, are given in full lines. In order to illustrate the difference between this method of analysis and the two-sieve method proposed by M. Feret, the curve representing the analysis by the latter method is plotted in each case in broken lines. The diameters of particles that would pass through the two sieves proposed by Feret are approximately 0.0125 and 0.0465 inch. Therefore, the broken lines are drawn from zero to the point at which the

full granularmetric analysis line crosses the ordinate at 0.0125; thence to the point at which the full granularmetric analysis line crosses the ordinate at 0.0465; and thence to 100 per cent at diameter 0.25, the latter being off the diagram. In Feret's method a $\frac{1}{3}$-inch sieve is used, but in the investigations reported in this bulletin, since the $\frac{1}{4}$-inch screen was used, the line is drawn in this way.

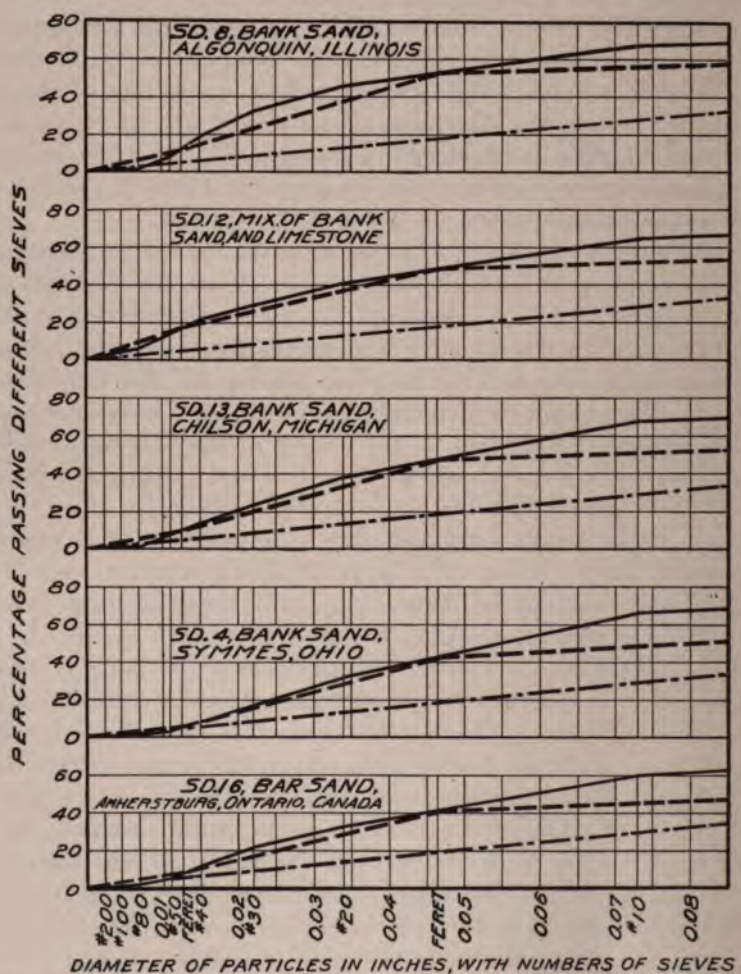
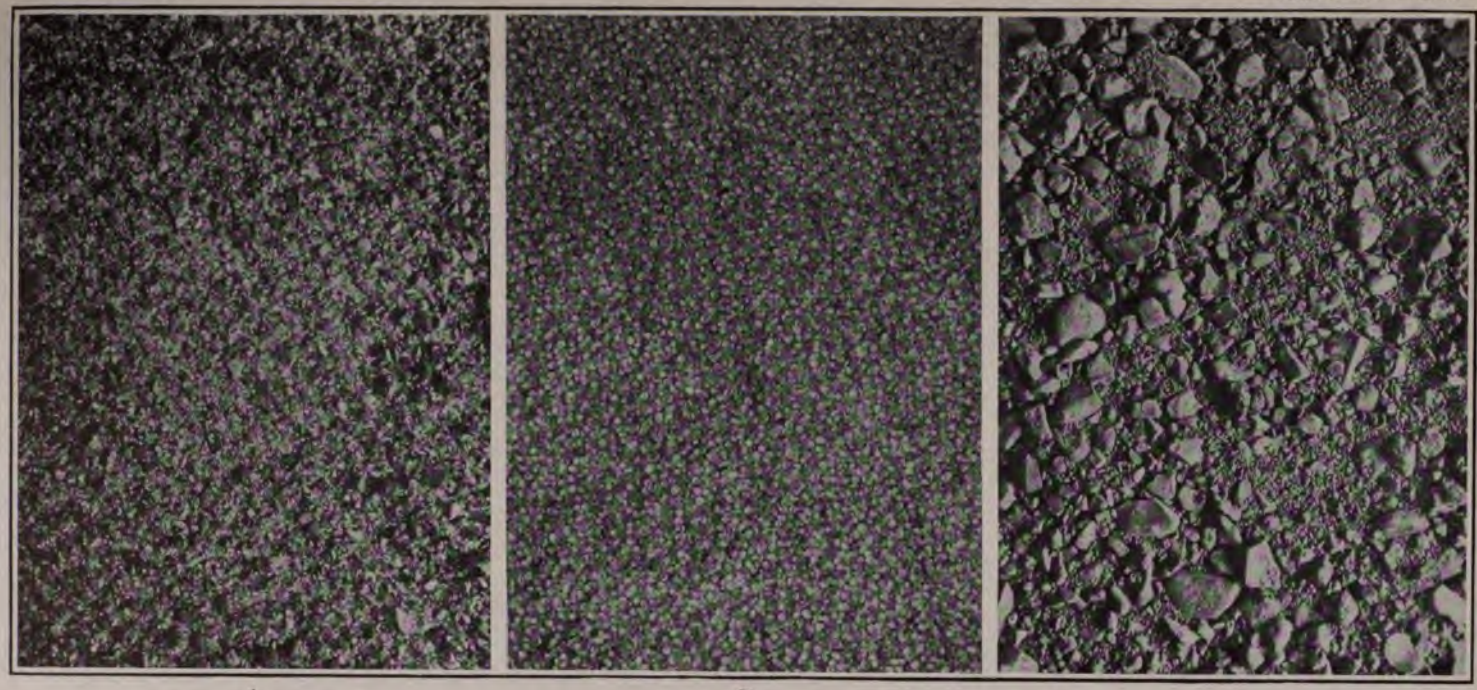


FIG. 13.—Granularmetric analysis curves for sands 8, 12, 13, 4, and 16. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Below the two curves just described is given the uniform-grade line in dots and dashes. It can be seen that in arranging from the finest to the coarsest sand the curves have been arranged in the order of the size of segment included between the granularmetric analysis curve and the uniform-grade line. In can also be seen that, as the



A *B* *C*

A. MERAMEC RIVER SAND, DRAKE, MO. (SAMPLE 22).
B. STANDARD OTTAWA SAND, OTTAWA, ILL.
C. BAR GRAVEL SCREENINGS, MERAMEC RIVER, DRAKE, MO. (SAMPLE 1).

segment decreases the sand gradually becomes coarser and approaches uniform grading more nearly.

Only that portion of each curve that shows the variation in grading under the No. 10 sieve, and for a short distance beyond it, is drawn in the figures. If the remainder of the curves were drawn there would simply be three straight lines from the line for the No. 10 sieve to 100 per cent at a diameter of 0.25. Instead of this, the lines to the right of the No. 10 ordinate are given the proper inclination and the remainder is omitted.

Comparison between measured and computed voids.—In the determination of the percentage of voids and the weight per cubic foot, three independent determinations were made. After each reading the material was thoroughly air dried for the next test.

On account of the great difficulty experienced in the determination of the percentage of voids, due to the flexibility in compacting the material, and to the contained moisture, great care was required in these determinations. Afterwards, the voids were computed from the specific gravity and weight per cubic foot.

On account of the fact that different methods of placing the material in the weighing cylinder result in different degrees of compactness, a uniform method of handling was adopted. This consists in allowing the material to fall from the same height and to fill the cylinder in a certain length of time.

The computed and measured voids are given in Table VIII (p. 59). The computed percentage of voids for any sand is found by first multiplying the specific gravity by the weight of a cubic foot of water. This gives the product "X" (column 10) in the table, which is the weight of a solid cubic foot of the material. The measured weight per cubic foot, W, is then divided by X to give the part of the space actually occupied by the sand grains (column 11). The difference between this quotient and one, multiplied by 100, gives the computed percentage of voids.

In columns 14 and 15 of the table are given the differences between the measured and computed values. In only two cases, namely, Sd. 7 and Sd. 16, are the measured voids an appreciable amount greater than the computed. Almost invariably the latter is the greater, but in more than two-thirds of the cases the difference is not more than 1 per cent. From the line marked "Average" it can be seen that the computed voids are 0.8 per cent greater than the measured.

Uniformity coefficient.—It is frequently necessary to draw comparisons between sands composed of grains of different sizes. It has been generally established that the strength quality or value of a sand may be indicated by ascertaining whether it lies in the coarse, medium, or fine region, and it is important to determine in some way the degree of coarseness or fineness. One method that suggests itself is to sift

the sand through the eight sieves that are used in the series of experiments under description, and then to plot the granularmetric analysis curve as has been done in this report. A direct comparison can then be made between any sands whose granularmetric analyses are known. Feret's two-sieve method for studying properties of sands has been already explained (p. 53). Another method of studying sands is by means of Hazen's uniformity coefficient.

Hazen suggested a factor equal to the ratio of the diameter of one particle (located by the intersection of the 60 per cent abscissa with the granularmetric analysis curve) to the diameter of another particle (located by the intersection of the 10 per cent abscissa with the curve); the size of the latter or smaller particles he terms the "effective size," and, inasmuch as this acts in the capacity of a divisor, its fluctuations affect the uniformity coefficient. When the curves show a general normal alignment through the two points mentioned above, the uniformity coefficient as thus obtained is a fair index of the relative grading of the sand.

The uniformity coefficients of the sand studied in this investigation are arranged progressively in decreasing order in Table XI (p. 62). The voids of each sand are also given for convenience of comparison. This uniformity coefficient does not appear to indicate the quality of a sand any better than the granularmetric analysis curves.

PHYSICAL TESTS OF SAND MORTARS.

Method.—Each of the sands described in the preceding pages was mixed with typical Portland cement to form mortars of different proportions, and these mortars were made into test pieces for the tensile, compressive, and transverse tests. Proportions of 1:3 and 1:4 were used in every case; in many other cases where there was sufficient material of one size this was tested as a 1:3 one-size mortar. For each sand 15 test pieces were made for each kind of stress, and three pieces were tested at each of the five ages, 7, 28, 90, 180, and 360 days.

The results of the strength tests on these mortars, including the register number, the yield at the 1:3 ratio, the register number of the corresponding typical Portland cement test pieces, the temperature (in °F.) of the water and of the air at the time of molding, the percentage of water used for normal consistency, and the breaking strengths (in pounds per square inch) at different ages are given in Table IX (p. 62). In giving the results of tests on 1:3 one-size mortar the size to which the sand was shifted is also shown. Table VIII (p. 59) summarizes data respecting the field origin and nature of each sand; and the average physical properties are given in Table XII (p. 78).

The yield of 1:3 mortar was determined in order to form a general basis as to the volume of mortar derived from a given volume of sand when mixed with cement in proportions of 1:3 by weight. This value is obtained by dividing the volume of mortar by the volume of the sand before mixing.

The results of the strength tests on neat cement test pieces made from the same cement used in the mortars are given in Table VII (p. 36) and are plotted in figs. 6, 7, and 8. The corresponding cement numbers found in the left-hand column of Table VII are also given in Table IX so that the strength of the mortar can be compared with the strength of the neat cement used in the mortar.

Tensile strength.—The results of the tensile tests on 1:3, on 1:4, and on 1:3 one-size sand mortar are given in Table IX*a* (p. 62). The results are arranged in groups of three, and the average of each group is shown in the line marked "Average."

The lack of uniformity in the increase of strength is probably due to physical differences in the sands. In general, the tensile strength of all three proportions seems to decrease with the increase in the voids. An increase in tensile strength is also noticeable as the sands approach uniform grading.

Compressive strength.—The results of the compressive tests are given in Table IX*b* (p. 67). The values in this table are in pounds per square inch and are obtained by dividing the total breaking load by the area of cross section of a 2-inch cube.

Considering these tests in the order of the percentage of voids, as arranged under tensile strength, we see that the strength appears to decrease with the increase of voids. The strength of mortars made from sands which have a small percentage of voids is in every case much greater than that of mortars made from sands having a large percentage of voids. The difference in strengths of the mortars of different proportions is also greater for those sands that have small percentages of voids. This condition is the same as that noticed in the study of tensile strength and indicates that the greatest compresive strength can be obtained by the use of a mortar in which the sand is uniformly graded.

Transverse strength.—The results of the transverse tests are given in Table IX*c* (p. 73). As stated elsewhere (p. 9), the values given in this table are moduli of rupture in pounds per square inch. These tests show the same tendency as in those for tensile and compressive strength. The strength of mortar made from those sands in which the percentages of voids are low, while not so marked as in the tension and compression tests, is greater than that of mortar made from sands in which the percentages of voids are high.

Summary of sand-mortar tests.—In general there is greater uniformity in tests made at the end of 180 days than in those made at

the end of the shorter periods. Alterations in environment materially affect the early strength, while the nature of the cement often causes irregularity in the strengths for the earlier periods. This irregularity disappears to a great extent as the test pieces become older, as is well illustrated in Tables III (p. 28), IV (p. 29), V (p. 31), and VI (p. 32), showing the percentage of gain in strength of tensile- and compressive-test pieces of neat cement and 1:3 standard-sand mortar. In that connection (p. 39) it was pointed out that, despite the many different strengths at 7 days and the many different percentages of gain to 28 and 90 days, the strengths at 180 days showed remarkable uniformity. In comparing the strength of mortars it is desirable to use the results of the 180-day tests.

The results of these tests seem to indicate that the nearer the grading curve approaches the uniform-grade line the greater is the strength. It is also apparent that the strength decreases with the increase in the percentage of voids.

Density.—The density of mortar made from each sand was determined in order to ascertain its relation to the other physical properties and to see if there is a relation between the density and the strength of the mortar. The density was determined for only the 1:3 mortar; in subsequent investigations density determinations are to be made for all proportions.

The method of making the density test is as follows: After the sand, cement, and water have been weighed in the required proportions and thoroughly intermixed, 1,000 grams of the mixture are introduced in portions of about 50 grams into a graduated cylinder of 500 cubic centimeters capacity. Each layer is tamped until the water flushes to the surface. The graduated cylinder is weighed before and after the mortar is introduced, the difference being the weight of the mortar. A reading on the top of the mortar is taken after the level of the top becomes stationary, generally within 30 minutes after the mortar is introduced.

The weight of sand and cement used is known from the amount introduced into the cylinder. The absolute volumes of these ingredients are then determined by their respective specific gravities.

Each of these absolute volumes is divided by the recorded volume of the mortar, and these ratios are termed the "elementary volumes" of cement and sand, being designated by "C" for cement and "S" for sand. The sum of the elementary volumes of cement and sand, or, using the suggested notation, "C+S," is termed the "density." In other words, density as applied to mortar signifies the ratio of the absolute volume of sand and cement to the recorded volume of the mortar.

The densities of 1:3 mortar and the relation between the densities and other physical properties of the sands and mortars are given in

Table XII (p. 78). In column 1 are given the register numbers of the sands used in the mortars whose densities are given in column 2. The densities are arranged in order, with the largest value at the top. For purposes of comparison the number of the granular metric analysis curve for each sand is given in column 3. The numbers start with No. 1 for Sd. 15 (at the top of fig. 9, p. 45) and end with No. 22 for Sd. 16 (at the bottom of fig. 13, p. 54). The percentage of voids, weight per cubic foot, and tensile, compressive, and transverse strengths of the corresponding mortars at 180 days are given in columns 4–8. It will be observed that in the upper part of the table, where the values of density are greatest, the percentages of voids are least and the weights per cubic foot and the strengths are greatest, and near the bottom the opposite is true.

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25.*

SANDS.

Register No.	Location.	Source of supply.	Specific gravity.	Weight per cubic foot (pounds).	Absorption (per cent). In 24 hours.	Absorption (per cent). In 48 hours.	Per cent of silt.
1	2	3	4	5	6	7	8
Sd. 1	Kansas City, Mo	Bar	2.64	109.3	0.36	0.42	0.20
Sd. 2	do	do	2.65	107.7	.36	.39	Trace.
Sd. 3	Columbus, Ohio	do	2.60	103.3			4.2
Sd. 4	Symmes, Ohio	Bank	2.63	116.4			1.4
Sd. 5	Cincinnati, Ohio	Bar	2.59	104.8	.93	1.06	Trace.
Sd. 6	St. Charles, Ill	Bank	2.67	113.5	1.48	2.11	.53
Sd. 7	Carpenterville, Ill	do	2.68	116.0	.95	.96	1.2
Sd. 8	Algonquin, Ill	do	2.68	114.5		1.31	1.3
Sd. 9	Libertyville, Ill	do	2.60	110.5	.92	1.39	2.6
Sd. 10	Kenton County, Ky	do	2.62	110.0	1.06	1.41	2.1
Sd. 11	Toledo, Ohio	Mixture of sand and limestone screenings.	2.71	108.3	3.05	3.63	3.4
Sd. 12	do		2.70	106.5			4.7
Sd. 13	Chilson, Mich	Bank	2.70	119.5	.61	1.63	.3
Sd. 14	St. Clair River, Mich	Bar	2.64	111.0	2.36	2.61	2.0
Sd. 15	do	do	2.63	95.5			2.2
Sd. 16	do	do	2.69	119.5	1.03	1.59	.23
Sd. 17	Utica, Mich	Bank	2.62	105.5		1.53	3.4
Sd. 18	Attica, Ind	do	2.64	106.5			3.9
Sd. 19	do	do	2.65	119.9	.64	1.19	.7
Sd. 20	do	do	2.63	116.5			1.3
Sd. 21	Moselle, Mo	Bar	2.61	89.0			Trace.
Sd. 22	Drake, Mo	do	2.60	98.8			Trace.

GRAVEL SCREENINGS.

Gl. 1	St. Louis, Mo	Bar	2.56	115.0	1.90	1.90	0.15
Gl. 2	Moselle, Mo	do	2.57	113.5	1.58	1.61	Trace.
Gl. 3	Columbus, Ohio	River bar	2.66	102.6	1.26	1.70	1.37
Gl. 4	Loveland, Ohio	Bank	2.67	117.1	.68	.72	2.7
Gl. 5	Carthage, Ohio	do	2.67	115.3	1.71	1.80	.04
Gl. 6	Ludlow, Ky	do	2.72	120.8	.95	1.02	2.85
Gl. 7	Chilson, Mich	do	2.68	113.4	.63	.71	.15
Gl. 8	do	do	2.70	111.5	1.31	1.31	.2
Gl. 9	Amherstburg, Canada	River beach	2.66	117.8	1.57	1.65	.71
Gl. 10	Lorain, Ohio	Lake beach	2.68	118.9	.5	.5	.4
Gl. 11	Attica, Ind	Bank	2.68	122.5	1.08	1.10	.3
Gl. 12	do	do	2.67	120.3	1.32	1.36	.5

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25*—Continued.

STONE SCREENINGS.

Register No.	Location.	Source of supply.	Specific gravity.	Weight per cubic foot (pounds).	Absorption (per cent). In 24 hours.	Absorption (per cent). In 48 hours.	Per cent of silt.
1	2	3	4	5	6	7	8
Se. 1	St. Louis, Mo	Limestone	2.70	103.5	0.64	0.67	4.90
Se. 2	do	do	2.70	106.2	.50	.55	5.40
Se. 3	do	do	2.67	103.5	1.28	1.31	2.30
Se. 4	Glencoe, Mo	do	2.65	105.5	.89	.91	.62
Se. 5	Springfield, Mo	do	2.66	95.7	.53	.55	1.00
Se. 6	Joplin, Mo	Chat	2.61	109.5	.75	.76	7.00
Se. 7	do	do	2.63	102.7	1.51	2.36	4.92
Se. 8	do	do	2.61	105.5	1.88	1.90	2.90
Se. 9	do	do	2.62	108.0	2.72	2.73	3.00
Se. 10	do	do	2.62	109.8	.82	1.05	4.73
Se. 11	St. Louis, Mo	Limestone	2.70	95.5	2.65	2.74	10.10
Se. 12	Kansas City, Mo	do	2.64	105.3	1.33	1.54	4.70
Se. 13	St. Joseph, Mo	do	2.71	102.2	1.65	1.79	2.20
Se. 14	Kansas City, Mo	do	2.64	104.3	1.40	1.42	4.00
Se. 15	Hoffman, Mo	Chat	2.84	109.5	1.25	1.28	.47
Se. 16	Bonneterre, Mo	do	2.86	120.0	1.12	1.13	3.72
Se. 17	Graniteville, Mo	Granite	2.70	108.8	.32	.32	1.40
Se. 18	Kankakee, Ill	Limestone	2.70	103.8	2.04	2.11	7.80
Se. 19	McCook, Ill	do	2.78	102.5	1.04	1.06	4.97
Se. 20	Columbus, Ohio	Bowlder	2.69	108.5	2.48	2.52	3.1
Se. 21	Hillsboro, Ohio	Limestone	2.71	97.4	.04	.04	3.12
Se. 22	Greenfield, Ohio	do	2.72	106.3	1.90	2.05	1.07
Se. 23	Casparis, Ohio	do	2.65	99.7	.04	.13	3.5
Se. 24	Sylvania, Ohio	do	2.72	101.1	1.81	1.86	1.1
Se. 25	Sibley, Mich	do	2.70	110.3	.....	.....	16.3

SANDS.

Register No.	Measured and computed voids. 62.355 × specific gravity = X (pounds).	W X	Computed voids $100\left(1-\frac{W}{X}\right)$.	Measured voids.	Excess. Computed.	Excess. Measured.	Percentage by weight of 500 grams. Retained on sieve No. — 10.	20.	30.	40.	50.	80.	100.	200.	Passing sieve No. 200.
1	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sd. 1	164.62	0.664	33.6	32.5	1.1	.....	3.2	10.3	29.3	29.8	5.7	2.2	3.4	14.8	0.9
Sd. 2	165.25	.652	34.8	34.9	.....	0.1	5.4	25.4	26.0	25.7	12.8	4.2	.4	.1	.....
Sd. 3	162.12	.637	36.3	36.1	.2	.....	24.7	23.2	15.0	13.2	9.4	6.6	1.9	1.9	3.3
Sd. 4	163.99	.710	29.0	28.0	1.0	.....	33.0	34.9	15.2	8.4	4.4	2.1	.4	.3	.9
Sd. 5	161.49	.649	35.1	34.6	.5	.....	18.5	22.7	19.7	23.4	11.4	3.3	.3	.1	.....
Sd. 6	166.48	.682	31.8	31.6	.2	.....	15.5	15.9	16.0	20.5	17.7	9.1	1.7	1.9	1.2
Sd. 7	167.11	.694	30.6	31.6	.....	1.0	7.4	14.4	17.0	23.3	21.4	12.0	1.9	1.1	.7
Sd. 8	167.11	.685	31.5	30.7	.8	.....	30.7	22.2	14.2	13.7	10.7	6.0	.9	.6	.6
Sd. 9	162.12	.682	31.8	31.4	.4	.....	31.1	17.3	12.2	15.0	14.4	6.5	1.0	.8	1.3
Sd. 10	163.37	.673	32.7	31.6	1.1	.....	6.4	12.0	14.3	18.6	21.5	18.0	4.6	3.0	1.2
Sd. 11	168.98	.641	35.9	36.0	.....	.1	32.4	20.9	9.7	8.1	8.8	10.9	3.3	2.3	3.0
Sd. 12	168.36	.633	36.7	35.5	1.2	.....	33.3	24.7	11.8	7.5	7.2	7.3	2.4	2.2	2.8
Sd. 13	168.36	.710	29.0	28.9	.1	.....	30.9	30.4	14.4	10.0	6.7	5.2	1.0	.4	.2
Sd. 14	164.62	.668	33.2	31.9	1.3	.....	7.4	21.4	12.0	13.3	15.3	15.2	6.7	5.7	2.1
Sd. 15	163.99	.582	41.8	40.5	1.3	.....	1.0	1.8	2.0	8.5	25.3	44.7	9.6	4.5	1.2

TABLE VIII.—*Physical properties of sands 1–22, gravel screenings 1–12, and stone screenings 1–25*—Continued.

SANDS—Continued.

Register No.	Measured and computed voids.						Percentage by weight of 500 grams.								
	62.355 × specific gravity = X (pounds).	$\frac{W}{X}$	Computed voids $100\left(1-\frac{W}{X}\right)$.	Measured voids.	Excess.		Retained on sieve No. —								Passing sieve No. 200.
					Computed.	Measured.	10.	20.	30.	40.	50.	80.	100.	200.	
1	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sd. 16	167.73	0.713	28.7	29.7	.....	1.0	39.5	27.5	11.6	9.4	6.8	3.0	0.8	0.4	0.3
Sd. 17	163.37	.646	35.4	34.5	.9	.....	8.4	7.5	7.8	14.3	24.2	25.4	6.1	3.6	1.8
Sd. 18	164.62	.647	35.3	34.0	1.3	.....	4.1	16.3	16.0	19.0	13.8	16.3	4.1	5.0	4.6
Sd. 19	165.25	.726	27.4	26.9	.5	.....	27.1	26.9	16.4	14.3	7.2	5.2	.8	.6	.7
Sd. 20	163.99	.710	29.0	28.0	1.0	.....	23.3	26.5	13.9	11.7	7.7	11.7	1.9	1.3	1.1
Sd. 21	162.75	.547	45.3	40.9	4.4	.....	1.0	7.3	7.6	20.0	43.5	18.0	1.6	.2	.1
Sd. 22	162.12	.609	39.1	36.4	2.7	.....	7.33	23.7	14.3	21.6	15.8	15.1	1.7	.5	.1
Average..	164.90	.662	33.8	33.0	1.1	.1	.....	.....	.....	.....	.....	.....	.....	.....	.....

GRAVEL SCREENINGS.

Gl. 1	.....	.....	28.0	29.0	.....	1.0	61.8	12.6	6.3	7.7	7.5	3.6	0.3	0.0	0.2
Gl. 2	.....	.....	29.2	31.0	.....	1.8	37.8	14.5	7.8	9.6	13.1	13.3	2.2	0.8	.9
Gl. 3	.....	.....	38.2	38.6	.....	.4	79.0	5.0	2.6	1.6	1.7	.9	.8	1.7	6.7
Gl. 4	.....	.....	29.7	30.9	.....	1.2	28.0	11.3	11.5	19.8	15.9	9.0	1.6	1.8	1.1
Gl. 5	.....	.....	30.7	29.7	1.0	.....	39.6	2.3	13.9	12.3	7.5	3.0	.4	.1	.1
Gl. 6	.....	.....	28.8	27.9	.9	.....	46.2	16.1	6.9	7.8	8.1	7.0	2.6	2.2	3.1
Gl. 7	.....	.....	32.1	32.8	.....	.7	95.5	4.5	.0	.0	.0	.0	.0	.0	.0
Gl. 8	.....	.....	33.8	34.8	.....	1.0	97.7	1.3	.0	.0	.0	.0	.0	.2	.8
Gl. 9	.....	.....	29.0	30.7	.....	1.7	99.3	.7	.0	.0	.0	.0	.0	.0	.0
Gl. 10	.....	.....	28.9	27.9	1.0	.....	33.2	16.0	9.3	10.1	14.3	14.7	1.4	.7	.3
Gl. 11	.....	.....	26.7	25.5	1.2	.....	45.3	26.1	13.7	7.1	4.0	2.3	.5	.2	.8
Gl. 12	.....	.....	27.8	26.5	1.3	.....	26.1	23.1	13.1	14.0	9.6	10.5	1.9	1.0	.7
Average..	.....	.....	.....	.....	1.1	1.1	.....	.....	.....	.....	.....	.....	.....	.....	.....

STONE SCREENINGS.

Se. 1	.....	.....	38.5	39.4	.....	0.9	36.8	22.5	12.3	7.8	5.4	5.4	2.7	4.9	2.2
Se. 2	.....	.....	36.9	37.2	.....	.3	40.5	21.1	10.0	7.7	5.1	4.9	2.1	5.6	3.0
Se. 3	.....	.....	37.8	37.0	0.8	.....	34.6	12.8	9.3	8.7	7.6	6.9	5.0	13.1	2.0
Se. 4	.....	.....	37.4	36.0	1.4	.....	73.9	6.0	5.2	3.0	2.2	2.2	1.5	4.5	1.5
Se. 5	.....	.....	42.3	41.1	1.2	.....	78.4	10.1	3.3	2.1	1.2	1.9	.9	.9	1.2
Se. 6	.....	.....	32.7	33.1	.....	.4	68.2	10.6	3.4	2.0	1.5	1.7	.8	2.4	9.4
Se. 7	.....	.....	37.1	36.1	1.0	.....	47.1	24.6	10.2	5.2	3.6	2.7	.9	1.9	3.8
Se. 8	.....	.....	35.2	34.6	.6	.....	51.3	21.1	8.4	4.9	3.7	3.8	1.5	2.2	3.1
Se. 9	.....	.....	33.9	33.0	.9	.....	53.6	18.5	7.8	4.8	3.9	4.0	1.5	2.5	3.4
Se. 10	.....	.....	32.8	31.8	1.0	.....	49.8	19.2	8.6	5.9	4.1	2.6	2.1	2.8	4.9
Se. 11	.....	.....	43.3	42.1	1.2	.....	9.9	40.3	13.7	7.9	7.2	7.9	3.6	18.5	1.0
Se. 12	.....	.....	36.0	35.1	.9	.....	31.2	23.6	11.0	7.4	5.2	6.5	1.9	11.3	1.9
Se. 13	.....	.....	39.5	38.2	1.3	.....	38.4	33.8	13.7	4.9	1.8	1.4	1.1	4.5	.4
Se. 14	.....	.....	36.6	35.8	.8	.....	54.9	19.0	7.4	4.3	2.8	2.8	1.4	3.9	3.5
Se. 15	.....	.....	35.9	37.0	.....	1.1	56.9	35.3	5.3	1.2	.3	.1	.0	.1	.3
Se. 16	.....	.....	32.7	32.1	.6	.....	27.4	34.2	14.5	8.4	5.5	4.4	1.4	1.5	1.6
Se. 17	.....	.....	.....	34.7	.....	.....	49.7	22.8	8.7	4.4	4.1	3.2	1.2	2.7	3.2
Se. 18	.....	.....	38.3	39.0	.....	.7	48.7	17.8	7.7	5.5	3.5	3.6	1.4	3.1	8.7
Se. 19	.....	.....	40.9	39.3	1.6	.....	22.9	37.6	13.5	8.9	4.1	3.1	1.3	3.1	5.5
Se. 20	.....	.....	.....	35.2	.....	.....	61.5	7.1	2.4	1.8	1.2	1.7	1.2	4.2	18.9
Se. 21	.....	.....	42.4	41.0	1.4	.....	5.8	14.1	8.5	8.8	10.1	13.6	9.4	14.1	15.3
Se. 22	.....	.....	37.3	37.5	.....	.2	44.4	21.4	8.5	4.9	3.4	3.0	1.5	3.0	9.9
Se. 23	.....	.....	39.7	38.2	1.5	.....	57.0	13.8	6.6	4.3	3.9	4.0	1.1	3.9	5.4
Se. 24	.....	.....	40.4	41.8	.....	1.4	87.0	6.8	1.5	.6	.5	.5	.0	.5	2.6
Se. 25	.....	.....	34.5	33.8	.7	.....	46.3	17.0	6.6	4.8	3.1	3.5	1.6	12.2	4.2
Average..	.....	.....	.....	.....	1.1	.7	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE IXa.—*Tensile strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1	1:3	1.18	79-15	71.0	69.0	8.9	390	505	485	420	377
							400	460	455	415	347
							379	475	480	410	380
	Average						390	480	473	415	368
	1:4		79-17	71.2	67.6	8.3	308	370	380	312	333
							285	365	400	310	318
							292	384	383	328	308
	Average						295	373	388	317	320
	1:3 (sifted)		79-26	69.8	68.0	8.9	287	371	435	297	307
							295	375	400	293	299
							310	360	425	340	212
	Average						297	369	420	310	273
Sd. 2	1:3	1.12	79-15	71.0	69.0	8.9	342	420	492	367	316
							357	435	490	370	343
							330	450	490	.....	300
	Average						343	435	491	369	320
	1:4		79-17	71.2	67.6	8.3	275	395	417	275	265
							302	420	395	280	249
							312	419	377	300	242
	Average						296	411	396	285	252
	1:3 (sifted)		79-27	70.7	64.4	8.9	317	335	392	312	272
							310	350	400	320	278
							308	315	.....	300	271
	Average						312	333	396	311	274
Sd. 3	1:3	1.09	79-28	71.0	59.2	8.9	395	557	505	480	537
							400	510	545	493	582
							380	500	495	512	575
	Average						392	522	515	495	565
	1:4		79-28	71.0	59.2	8.3	335	400	500	402	473
							350	435	542	415	432
							341	417	510	415	445
	Average						342	417	517	411	450
	1:3 (sifted)		79-28	71.0	59.2	8.9	212	354	380	400	410
							218	346	360	370	365
							220	350	365	365	384
	Average						217	350	368	378	386
Sd. 4	1:3	1.14	75-32	70.7	62.6	8.9	533	595	743	717	783
							539	630	738	760	720
							490	630	785	716	815
	Average						521	618	755	731	773
	1:4		79-32	70.7	62.6	8.3	367	505	690	638	615
							373	560	644	640	648
							380	560	645	632	658
	Average						373	542	660	637	640
	1:3 (sifted)		79-32	70.7	62.6	8.9	327	407	470	421	455
							320	405	503	426	470
							316	365	512	453	483
	Average						321	392	495	433	469

[a] For details of field origin of sand samples see pp. 43-52.
[b] In tests marked "sifted" the sand used was sifted through No. 30 and over No. 40 size.

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 5	1:3	1.11	79-29	70.7	70.7	8.9	418	475	580	401	444
							424	511	551	420	410
							388	510	535	440	392
	Average						410	499	555	420	415
	1:4		79-29	70.7	70.7	8.3	325	371	475	311	319
							335	400	485	342	362
							295	362	445	310	334
	Average						318	378	468	321	338
	1:3 (sifted)		79-29	70.7	70.7	8.9	282	332	400	280	308
							277	325	375	300	324
							295	322	405	285	351
	Average						285	326	393	288	328
Sd. 6	1:3	1.14	79-40	69.8	70.0	8.9	500	633	715	638	752
							475	607	690	629	770
							495	625	710	574	741
	Average						490	622	705	614	754
	1:4		79-40	69.8	70.0	8.3	438	530	626	540	660
							420	520	605	500	619
							423	530	580	510	634
	Average						427	527	604	517	638
	1:3 (sifted)		79-40	69.8	70.0	8.9	327	380	440	316	453
							300	385	470	390	421
							306	422	430	324	440
	Average						311	396	447	343	438
Sd. 7	1:3	1.22	79-42	69.8	64.4	8.9	430	507	540	572	628
							420	533	512	655	632
							400	540	505	582	645
	Average						417	527	519	603	635
	1:4		79-42	69.8	64.4	8.3	310	460	410	430	524
							320	455	370	484	522
							280	410	398	473	497
	Average						303	442	393	462	514
	1:3 (sifted)		79-42	69.8	64.4	8.9	285	423	367	414	460
							325	467	392	370	442
							290	420	405	390	449
	Average						300	437	388	391	450
Sd. 8	1:3	1.16	79-43	68.0	68.0	8.9	540	605	730	757	706
							560	645	758	704	678
							535	635	747	700	682
	Average						545	628	745	720	689
	1:4		79-43	68.0	68.0	8.3	420	562	570	570	586
							403	515	565	586	624
							418	522	550	.....	639
	Average						414	533	562	578	620
	1:3 (sifted)		79-43	68.0	68.0	8.9	320	420	406	397	427
							310	425	410	412	421
							290	425	425	.....	415
	Average						307	423	414	404	421

TABLE IX*a*.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 9	1:3	1.16	79–45	68.0	64.4	8.9	390	504	481	486	507
							400	470	490	470	532
							412	505	515	492	536
	Average						401	493	495	483	525
	1:4		79–45	68.0	64.4	8.3	325	428	428	422	415
							304	397	437	460	415
							308	410	400	442	413
	Average						312	412	422	441	414
	1:3 (sifted)		79–45	68.0	64.4	8.9	274	385	351	387	452
							291	370	354	365	421
							304	376	352	376	447
	Average						290	377	352	376	440
Sd. 10	1:3	1.18	79–39	71.5	70.0	8.9	392	550	680	486	610
							430	549	640	487	585
							412	541	657	491	592
	Average						411	547	659	488	596
	1:4		79–39	71.5	70.0	8.3	341	460	540	395	428
							325	400	513	396	452
							320	410	517	410	454
	Average						329	423	523	400	445
	1:3 (sifted)		79–39	71.5	70.0	8.9	328	380	473	396	405
							318	390	460	372	368
							300	440	452	349	398
	Average						315	403	462	372	390
Sd. 11	1:3	1.13	79–46	71.6	71.6	8.9	434	600	647	662	727
							429	606	.....	725	748
							420	600	655	737	730
	Average						428	602	651	708	735
	1:4		79–46	71.6	71.6	8.3	353	512	505	703	690
							373	514	542	710	670
							350	531	530	708	687
	Average						359	519	526	707	682
	1:3 (sifted)		79–46	71.6	71.6	8.9	334	442	420	650	621
							345	463	460	575	606
							332	463	461	589	588
	Average						337	456	447	605	605
Sd. 12	1:3	1.12	79–47	68.0	64.0	8.9	405	605	610	591	807
							400	605	627	598	811
							415	580	630	614	799
	Average						407	597	622	601	806
	1:4		79–47	68.0	64.4	8.3	342	506	600	640	636
							331	504	585	655	681
							366	534	593	645	656
	Average						346	515	593	647	658
	1:3 (sifted)		79–47	68.0	64.4	8.9	265	320	370	405	512
							267	300	372	435	489
							270	310	370	415	486
	Average						267	310	371	418	496

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 13..	1:3	1.21	79-50	69.8	59.0	8.9	547	600	661	631	796
							560	580	650	695	750
							522	575	.....	679	787
	Average						543	585	655	668	778
	1:4		79-50	69.8	59.0	8.3	431	520	548	547	673
							456	475	575	536	695
							.....	492	565	530	706
	Average						444	496	559	538	691
Sd. 14..	1:3	1.19	79-52	69.8	68.0	8.9	430	444	425	475	588
							415	450	425	482	571
							.....	437	450	494	578
	Average						422	444	433	484	579
	1:4		79-52	69.8	68.0	8.3	295	321	376	385	408
							315	324	355	376	410
							295	350	343	398	415
	Average						302	332	358	386	411
	1:3 (sifted)		79-52	69.8	68.0	8.9	319	332	348	379	387
							298	369	360	367	406
							325	345	345	382	415
	Average						314	349	351	376	403
Sd. 15..	1:3	1.13	79-53	69.8	66.2	8.9	320	336	367	343	386
							300	343	380	331	374
							315	325	.....	319	370
	Average						312	335	374	331	377
	1:4		79-53	69.8	66.2	8.3	250	285	266	294	280
							255	276	271	317	325
							231	258	261	302	312
	Average						245	273	266	304	306
	1:3 (sifted)		79-53	69.8	66.2	8.9	269	313	330	315	335
							255	320	330	348	324
							240	285	307	326	341
	Average						255	306	322	330	333
Sd. 16..	1:3	1.20	79-54	69.2	75.2	8.9	488	515	595	583	661
							461	530	573	611	648
							465	510	575	621	640
	Average						471	518	581	605	650
	1:4		79-54	69.8	75.2	8.3	446	440	535	540	521
							420	475	420	567	555
							457	481	515	551	550
	Average						441	465	490	553	542
	1:3 (sifted)		135-20				376	462	472	584	.....
							389	431	495	571	.....
							380	496	522	562	.....
	Average						382	463	496	572	.....

TABLE IXa.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 17	1:3	1.27	79-56	71.6	64.2	8.9	338	380	438	436	485
							344	345	420	473	470
							348	357	450	489	468
	Average						343	361	436	466	474
	1:4		79-56	71.6	64.2	8.3	285	318	360	386	430
							292	317	345	375	406
							270	321	330	399	412
	Average						282	319	345	387	416
	1:3 (sifted)		79-56	71.6	64.2	8.9	308	333	383	341	389
							300	345	382	362	395
							330	347	360	350	387
	Average						313	342	375	351	390
Sd. 18	1:3	1.15	133-5	68.0	78.8	8.9	351	450	496	575	542
							364	500	506	540	560
							382	480	540	534	564
	Average						366	477	514	550	555
	1:4		133-5	68.0	78.8	8.3	300	400	460	452	464
							337	355	457	485	462
							320	405	497	477	456
	Average						319	387	471	471	461
	1:3 (sifted)		133-5	68.0	78.8	8.9	228	329	330	376	426
							255	310	377	330	397
							232	350	351	343	408
	Average						238	330	353	350	410
Sd. 19	1:3	1.19	133-17	68.9	67.1	8.9	534	635	703	792	799
							515	647	663	780	781
							555	680	659	746	842
	Average						535	654	675	773	807
	1:4		133-17	68.9	67.1	8.3	492	515	530	665	592
							485	500	528	615	700
							450	490	.....	633	653
	Average						476	502	529	638	648
	1:3 (sifted)		133-17	68.9	67.1	8.9	265	317	376	426	383
							282	340	346	388	359
							290	320	336	382	353
	Average						279	326	353	399	363
Sd. 20	1:3	1.16	133-21	69.8	78.8	8.9	455	548	624	632	648
							446	565	573	673	760
							420	556	.....	706	700
	Average						440	556	598	670	703
	1:4		133-21	69.8	78.8	8.3	384	498	571	610	566
							375	466	535	544	480
							355	499	562	562	540
	Average						371	488	556	572	529
	1:3 (sifted)		135-23			8.9	337	347	332	423	571
							320	395	368	422	578
							309	398	380	436	566
	Average						322	380	360	427	572

TABLE IX*a*.—*Tensile strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 21..	1:3	1.05	133-3	63.0	67.1	8.9	285	361	350	405	389
							275	357	336	373	397
							300	350	337	362	383
	Average						287	356	341	380	390
	1:4		133-3	63.0	67.1	8.3	210	256	243	300	275
							203	250	293	308	264
							200	247	260	280	275
	Average						204	251	265	296	271
	1:3 (sifted)		133-3	63.0	67.1	8.9	232	282	283	337	337
							285	282	290	294	320
							260	311	300	280	329
	Average						259	292	291	304	329
Sd. 22..	1:3	1.11		68.0	71.0	11.5	285	454	440	462	.....
							276	439	438	490	.....
							272	432	470	510	.....
	Average						277	442	449	487	.....
	1:4			68.0	71.0	11.0	188	318	367	414	.....
							194	311	368	375	.....
							200	323	377	391	.....
	Average						194	317	371	393	.....
	1:3 (sifted)			68.0	65.0	11.5	225	307	358	375	.....
							235	310	365	372	.....
							217	315	360	354	.....
	Average						226	311	361	367	.....

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1...	1:3	1.18	79-5	70.0	64.4	8.9	1,200	2,200	3,642	3,630	4,475
							1,250	2,112	3,475	3,570	4,200
							1,147	2,137	3,500	3,830	4,150
	Average						1,199	2,150	3,539	3,677	4,275
	1:4		79-12	68.0	60.8	8.3	932	1,375	2,488	2,850	3,000
							875	1,562	2,313	2,818	2,900
							852	1,412	2,488	2,813	3,200
	Average						886	1,450	2,430	2,825	3,033
	1:3 (sifted)		79-21	69.8	68.0	8.9	1,325	2,077	2,790	2,825	3,425
							1,275	2,187	2,570	3,125	3,500
							1,272	2,192	3,170	2,775	3,350
	Average						1,291	2,152	2,843	2,908	3,425
Sd. 2...	1:3	1.12	79-5	70.0	64.4	8.9	1,625	3,212	4,667	5,285	5,800
							1,795	3,700	4,630	5,538	5,725
							1,715	3,367	4,875	5,258	5,650
	Average						1,712	3,426	4,724	5,360	5,725
	1:4		79-13	68.0	73.4	8.3	1,100	2,025	2,745	3,150	3,975
							1,037	2,000	2,500	3,025	3,750
							1,012	2,162	2,500	.....	3,600
	Average						1,050	2,062	2,582	3,088	3,775
	1:3 (sifted)		79-22	70.7	64.4	8.9	1,200	1,900	2,100	2,515	3,050
							1,125	1,930	2,545	2,488	2,750
							1,105	1,862	2,500	2,610	2,925
	Average						1,143	1,897	2,382	2,538	2,908

[a] For details of field origin of sand samples see pp. 43-52.
[b] In tests marked "sifted" all sand used was sifted through No. 30 and over No. 40 size.

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 3..	1:3	1.12	79-23	73.4	71.6	8.9	2,012	3,722	4,608	5,088	6,140
							1,987	3,750	4,850	5,578	6,062
							2,002	3,720	5,113	5,173	6,202
	Average						2,000	3,731	4,857	5,280	6,135
	1:4		79-23	73.4	71.6	8.3	1,167	2,618	3,470	3,778	4,135
							1,092	2,825	3,725	4,043	4,850
							1,225	2,385	3,453	3,780	4,335
	Average						1,161	2,609	3,549	3,867	4,440
	1:3 (sifted)		135-24	78.8	71.6	11.5	.....	2,225	3,550	3,300	.....
							1,775	2,600	3,400	3,175	.....
							1,675	.....	3,300	2,475	.....
	Average						1,725	2,412	3,417	2,983	.....
Sd. 4...	1:3	1.12	79-27	70.7	62.6	8.9	3,275	5,220	5,975	5,935	7,825
							3,168	4,838	6,075	6,275	8,100
							3,225	4,975	6,288	.....	8,075
	Average						3,223	5,011	6,113	6,105	8,000
	1:4		79-27	70.7	62.6	8.3	1,968	2,908	4,453	.....	5,050
							1,838	3,225	4,388	3,930	5,525
							1,750	3,000	4,530	4,335	5,300
	Average						1,852	3,044	4,457	4,133	5,292
	1:3 (sifted)		135-25	78.8	71.6	10.1	.....	2,700	4,375	3,713	.....
							1,450	2,025	4,600	3,500	.....
							1,475	.....	.....	3,750	.....
	Average						1,462	2,362	4,488	3,654	.....
Sd. 5...	1:3	1.11	79-24	70.7	62.6	8.9	2,250	2,500	4,363	4,925	1,850
							2,300	2,375	4,613	4,750	1,812
							2,057	2,613	4,523	4,580	2,000
	Average						2,202	2,496	4,500	4,752	1,887
	1:4		79-24	70.7	62.6	8.3	1,427	1,920	3,215	3,608	2,048
							1,412	2,000	3,225	3,605	2,088
							1,350	2,188	3,000	3,628	2,253
	Average						1,396	2,036	3,147	3,614	2,130
	1:3 (sifted)		79-24	70.7	62.6	8.9	1,425	1,258	2,100	2,870	1,848
							1,375	1,335	2,225	2,695	2,185
							1,300	1,373	2,250	2,538	2,250
	Average						1,367	1,322	2,192	2,701	2,094
Sd. 6...	1:3	1.14	79-40	71.6	71.6	8.9	2,658	3,995	3,050	4,425	4,950
							2,675	4,208	3,490	3,975	4,850
							2,725	4,093	3,168	4,275	5,112
	Average						2,686	4,099	3,236	4,225	4,971
	1:4		79-40	71.6	71.6	8.3	1,790	2,460	2,650	3,100	4,000
							1,658	2,525	2,850	3,325	.....
							1,678	2,718	2,722	3,200	3,825
	Average						1,709	2,568	2,741	3,208	3,912
	1:3 (sifted)		79-40	71.6	71.6	8.9	1,163	1,893	1,565	2,175	2,800
							1,220	1,720	1,585	2,300	3,050
							1,275	1,770	1,500	2,325	2,925
	Average						1,219	1,794	1,550	2,267	2,925

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 7	1:3	1.22	79-42	68.0	68.0	8.9	1,600	3,380	5,100	5,650	5,600
							1,575	3,513	4,585	5,650	5,950
							1,500	3,353	5,195	5,900	5,475
	Average						1,558	3,415	4,959	5,733	5,675
	1:4		79-42	68.0	68.0	8.3	1,080	2,200	3,418	3,175	4,175
							1,158	2,038	3,303	3,500	4,400
							1,058	2,388	3,625	3,325	4,375
	Average						1,098	2,209	3,449	3,333	4,317
	1:3 (sifted)		79-42	68.0	68.0	8.9	1,263	2,375	3,238	3,325	4,125
							1,163	2,175	2,975	3,675	4,100
							1,183	2,288	3,093	3,475	4,050
	Average						1,203	2,279	3,102	3,492	4,092
Sd. 8	1:3	1.16	79-43	64.4	64.4	8.9	2,403	5,670	5,825	7,512	7,125
							2,408	5,410	5,950	7,525	8,000
							2,520	5,388	6,225	7,625	7,075
	Average						2,444	5,489	6,000	7,554	7,400
	1:4		79-43	64.4	64.4	8.3	1,633	3,675	4,250	4,902	4,725
							1,690	4,000	4,100	5,608	4,550
							1,760	3,918	3,975	5,068	4,400
	Average						1,694	3,864	4,108	5,193	4,558
	1:3 (sifted)		79-43	64.4	64.4	8.9	1,263	1,743	1,750	2,425	3,175
							1,265	1,600	1,675	2,388	2,950
							1,168	1,738	.....	2,638	2,900
	Average						1,232	1,694	1,712	2,484	3,008
Sd. 9	1:3	1.16	79-45	68.0	64.4	8.9	2,230	3,745	5,825	2,950	6,000
							2,000	3,328	5,288	2,815	5,925
							2,038	3,410	.....	3,038	5,650
	Average						2,089	3,494	5,557	2,934	5,858
	1:4		79-45	68.0	64.4	8.3	1,460	2,608	3,163	2,650	4,175
							1,375	2,728	3,000	2,262	4,100
							1,423	2,500	3,513	3,022	3,875
	Average						1,419	2,612	3,225	2,645	4,050
	1:3 (sifted)		79-45	68.0	64.4	8.9	900	1,500	1,750	2,288	3,100
							850	1,475	1,875	2,370	2,925
							845	.....	.....	2,358	3,000
	Average						865	1,488	1,812	2,339	3,008
Sd. 10	1:3	1.18	79-39	69.8	67.1	8.9	1,623	3,120	4,425	4,705	5,975
							1,688	2,840	4,500	4,600	5,775
							1,750	2,648	.....	4,612	5,700
	Average						1,687	2,869	4,462	4,639	5,817
	1:4		79-39	69.8	67.1	8.3	1,050	1,895	2,263	2,650	3,800
							1,163	1,945	2,470	2,668	3,900
							1,063	1,792	2,288	2,750	3,675
	Average						1,092	1,877	2,340	2,689	3,792
	1:3 (sifted)		79-39	69.8	67.1	8.9	930	1,408	2,288	2,282	2,175
							933	1,480	2,238	2,462	2,300
							925	1,512	2,413	.....	2,050
	Average						929	1,467	2,313	2,372	2,175

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 11..	1:3	.....	79-46	68.0	64.4	8.9	2,025	5,358	5,863	5,050	5,925
							2,045	5,208	5,650	5,125	5,450
							2,213	5,300	5,563	5,025	5,600
	Average	.....	.....	.....	.....	.....	2,094	5,289	5,692	5,067	5,658
	1:4	.....	79-46	68.0	64.4	8.3	2,113	3,885	4,450	5,000	4,700
							1,988	4,015	4,038	5,200	4,975
							2,000	3,583	4,375	4,550	4,800
	Average	.....	.....	.....	.....	.....	2,034	3,811	4,288	4,917	4,825
	1:3 (sifted)	.....	79-46	68.0	64.4	8.9	1,038	2,335	3,238	2,225	3,200
							1,045	2,198	.....	1,875	2,975
							1,045	.....	3,128	1,800	3,075
	Average	.....	.....	.....	.....	.....	1,043	2,266	3,183	1,967	3,083
Sd. 12..	1:3	1.12	79-47	69.8	62.6	8.9	2,550	4,250	6,438	.....	6,600
							2,263	4,240	6,083	6,000	6,800
							2,480	.....	6,213	6,250	6,975
	Average	.....	.....	.....	.....	.....	2,431	4,245	6,245	6,125	6,792
	1:4	.....	79-47	69.8	62.6	8.3	1,875	2,750	3,875	3,700	4,450
							1,788	2,973	4,235	3,950	4,225
							2,000	2,795	3,975	3,825	4,225
	Average	.....	.....	.....	.....	.....	1,888	2,839	4,028	3,825	4,300
	1:3 (sifted)	.....	79-47	69.8	62.6	8.9	1,260	1,500	1,975	850	2,750
							1,200	1,550	2,025	1,100	2,812
							1,250	1,525	.....	1,100	2,925
	Average	.....	.....	.....	.....	.....	1,237	1,525	2,000	1,017	2,829
Sd. 13..	1:3	1.21	79-50	69.8	60.0	8.9	3,200	5,633	5,637	7,500	6,775
							3,138	5,575	6,375	7,000	6,550
							3,188	5,538	5,685	7,050	6,887
	Average	.....	.....	.....	.....	.....	3,175	5,582	5,899	7,183	6,737
	1:4	.....	79-50	69.8	60.0	8.3	2,888	4,348	4,135	5,550	4,125
							3,000	4,708	4,737	5,550	4,375
							2,700	4,250	4,425	5,375	4,425
	Average	.....	.....	.....	.....	.....	2,863	4,435	4,432	5,492	4,308
Sd. 14..	1:3	1.19	79-52	68.9	68.2	8.9	1,875	3,188	3,708	4,350	4,000
							1,938	3,138	3,425	3,850	3,800
							.....	3,150	3,475	4,025	4,062
	Average	.....	.....	.....	.....	.....	1,906	3,159	3,536	4,075	3,954
	1:4	.....	79-52	68.9	68.2	8.3	1,350	1,900	2,650	2,725	3,200
							1,413	2,088	2,875	2,250	3,300
							1,350	1,830	.....	2,375	3,250
	Average	.....	.....	.....	.....	.....	1,371	1,939	2,763	2,450	3,250
	1:3 (sifted)	.....	79-52	68.9	68.2	8.9	1,380	1,988	2,675	3,075	2,900
							1,488	1,895	2,638	3,000	2,900
							1,475	2,025	2,825	2,750	3,000
	Average	.....	.....	.....	.....	.....	1,448	1,969	2,713	2,942	2,933

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 15	1:3	1.13	79-53	69.8	68.0	8.9	1,243	1,860	2,012	2,800	2,750
							1,263	1,900	2,000	2,575	2,687
							1,280	1,933	2,087	2,525	2,750
	Average						1,262	1,898	2,033	2,633	2,729
	1:4		79-53	69.8	68.0	8.3	995	1,388	1,500	1,875	1,950
							908	1,345	1,488	1,725	1,925
							958	1,328	1,675	1,900	2,000
	Average						954	1,352	1,554	1,833	1,958
	1:3 (sifted)		79-53	69.8	68.0	8.9	1,150	1,610	2,025	2,200	2,000
							1,108	1,548	2,088	2,050	2,050
							1,070	1,500	1,800	1,950	2,062
	Average						1,109	1,553	1,971	2,067	2,037
Sd. 16	1:3	1.20	79-54	69.8	65.3	8.9	3,025	5,525	5,062	7,225	6,750
							3,375	5,675	5,975	7,150	6,625
							3,285	5,813	5,538	6,950	6,862
	Average						3,228	5,671	5,525	7,108	6,742
	1:4		79-54	69.8	65.3	8.3	2,388	3,525	3,750	4,375	4,787
							2,440	3,675	4,250	4,750	4,675
							2,300	3,838	.....	4,725	4,800
	Average						2,376	3,679	4,000	4,617	4,754
	1:3 (sifted)		135-20				2,225	3,225	3,475	3,513	.....
							2,200	3,575	2,900	3,025	.....
							2,225	3,175	3,375	3,725	.....
	Average						2,217	3,325	3,250	3,421	.....
Sd. 17	1:3	1.27	79-56	71.6	67.1	8.9	1,940	3,143	4,225	4,700	4,887
							1,850	3,100	3,755	4,475	4,725
							1,933	3,093	3,875	5,050	4,687
	Average						1,908	3,112	3,952	4,742	4,766
	1:4		79-56	71.6	67.1	8.3	1,345	2,385	2,625	3,275	3,425
							1,338	2,263	2,562	3,475	3,500
							1,280	2,368	2,650	3,250	3,612
	Average						1,321	2,339	2,612	3,333	3,512
	1:3 (sifted)		79-56	71.6	67.1	8.9	1,408	2,440	2,610	3,275	3,400
							1,348	2,250	2,600	3,050	3,412
							1,363	2,418	2,538	3,000	3,600
	Average						1,373	2,369	2,583	3,108	3,471
Sd. 18	1:3	1.15	133-5	67.1	68.0	8.9	1,513	3,183	3,950	3,800	4,425
							.....	2,888	4,075	3,150	4,550
							1,613	3,188	.....	4,050	4,450
	Average						1,563	3,086	4,012	3,667	4,475
	1:4		133-5	67.1	68.0	8.3	1,335	1,988	.....	3,225	3,175
							1,380	2,130	2,000	3,000	3,100
							1,275	2,125	2,075	2,975	3,150
	Average						1,330	2,081	2,038	3,067	3,142
	1:3 (sifted)		133-5	67.1	68.0	8.9	1,158	1,500	1,950	2,050	2,725
							1,175	1,638	2,008	2,350	2,650
							1,113	.....	2,000	2,300	2,650
	Average						1,149	1,569	1,986	2,233	2,675

TABLE IX*b*.—*Compressive strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 19	1:3	1.19	133-17	68.9	77.0	8.9	4,475	5,620	6,325	6,525	7,900
							4,128	5,425	5,100	6,575	8,400
							4,138	5,755	5,700	7,050	6,950
	Average						4,247	5,600	5,708	6,719	7,750
	1:4		133-17	68.9	77.0	8.3	2,588	2,825	5,675	5,350	4,950
							2,305	3,110	4,225	4,950	4,200
							2,320	2,750	3,775	5,250	5,250
	Average						2,404	2,895	4,558	5,183	4,800
	1:3(sifted)		135-26	78.8	71.6	11.0	2,125	2,375	2,550	3,900	.....
							1,875	2,400	2,475	3,488	.....
							1,875	2,425	.....	3,475	.....
	Average						1,958	2,400	2,512	3,621	.....
Sd. 20	1:3	1.16	133-21	69.8	73.4	8.9	3,443	5,218	5,150	5,800	5,450
							3,565	5,140	4,800	6,500	7,025
							3,703	5,148	5,375	6,300	7,000
	Average						3,570	5,169	5,108	6,200	6,492
	1:4		133-21	69.8	73.4	8.3	2,025	3,200	3,575	4,725	5,200
							2,253	3,258	3,550	5,050	4,800
							2,000	3,013	4,050	5,500	4,550
	Average						2,093	3,157	3,725	5,092	4,850
	1:3 (sifted)		135-23	78.8	72.5	8.9	1,450	2,400	3,650	3,550	.....
							1,425	2,300	3,525	3,650	.....
							1,500	2,550	3,375	3,375	.....
	Average						1,458	2,417	3,517	3,525	.....
Sd. 21	1:3	1.05	133-3	63.5	74.0	8.9	1,600	2,353	2,920	2,550	3,300
							1,500	2,145	2,620	3,000	3,375
							1,545	2,250	2,600	3,125	3,325
	Average						1,548	2,249	2,713	2,892	3,333
	1:4		133-3	63.5	74.0	8.3	1,065	1,300	1,762	1,825	2,350
							1,078	1,210	1,945	1,850	2,250
							.....	1,203	.....	2,250	2,500
	Average						1,071	1,238	1,853	1,975	2,367
	1:3 (sifted)		133-3	63.5	74.0	8.9	1,020	1,663	1,900	2,175	2,525
							1,015	1,660	1,670	2,325	2,562
							1,093	1,583	1,912	2,400	2,650
	Average						1,043	1,635	1,827	2,300	2,579
Sd. 22	1:3	1.11	.....	71.0	68.8	11.5	2,375	4,075	5,625	5,125	.....
							2,250	4,175	5,650	4,900	.....
							2,325	4,050	5,425	4,850	.....
	Average						2,317	4,100	5,570	4,958	.....
	1:4			71.0	68.0	11.0	1,375	2,450	3,625	3,600	.....
							1,375	2,350	3,900	3,675	.....
							1,325	2,375	3,812	3,550	.....
	Average						1,358	2,395	3,780	3,608	.....
	1:3 (sifted)			68.0	65	11.5	1,425	2,750	3,400	3,550	.....
							1,400	2,700	3,450	3,500	.....
							1,425	2,650	3,375	3,675	.....
	Average						1,417	2,700	3,408	3,575	.....

TABLE IXc.—*Transverse strength of the mortars of 22 sands.*

Register No.[a]	Ratio of cement to sand.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 1	1:3	1.18	133-36	70.7	64.4	8.9	576	792	972	1,116	1,044
							720	774	864	1,008	1,116
							630	774	756	1,044	1,062
	Average						642	780	864	1,056	1,074
	1:4		133-37	69.8	64.2	8.3	504	648	756	918	792
							468	666	576	918	.....
							504	684	594	.....	.....
	Average						492	666	642	918	792
	1:3 (sifted)		133-38	68.9	65.3	8.9	468	648	648	882	810
							450	612	684	828	828
							504	522	.....	864	792
	Average						474	594	666	858	810
Sd. 2	1:3	1.12	133-39	71.6	71.6	8.9	648	846	684	972	1,008
							666	810	666	1,008	1,044
							666	738	702	720	972
	Average						660	798	684	900	1,008
	1:4		133-41	71.6	69.8	8.3	504	.....	666	828	468
							414	666	594	756	396
							432	558	612	774	.....
	Average						450	612	624	786	432
	1:3 (sifted)		133-42	69.8	68.9	8.9	450	558	576	792	864
							360	504	684	846	864
							324	702	738	702	828
	Average						378	588	666	780	852
Sd. 3	1:3	1.09	136-9	.....	.....	8.9	720	918	1,116	1,134	.....
							720	828	1,224	1,224	.....
							684	900	1,224	1,188	.....
	Average						708	882	1,188	1,182	.....
	1:4		136-8	.....	.....	8.3	522	630	846	1,116	.....
							540	630	936	1,170	.....
							522	702	846	1,116	.....
	Average						528	654	876	1,134	.....
Sd. 4	1:3	1.14	136-10	.....	.....	8.9	1,152	1,152	1,278	1,206	.....
							1,098	1,080	1,368	1,242	.....
							1,008	1,116	1,296	1,224	.....
	Average						1,086	1,116	1,314	1,224	.....
	1:4		136-11	.....	.....	8.3	756	828	1,098	1,224	.....
							684	864	1,152	1,188	.....
							630	720	1,044	1,296	.....
	Average						690	804	1,098	1,236	.....
Sd. 5	1:3	1.11	136-12	.....	.....	8.9	576	756	990	972	.....
							612	738	1,080	1,044	.....
							594	756	1,098	936	.....
	Average						594	750	1,056	984	.....
	1:4		136-13	.....	.....	8.3	504	558	738	846	.....
							450	576	648	864	.....
							540	540	684	.....	.....
	Average						498	558	690	855	.....

[a] For details of field origin of sand samples see pp. 43-52.
[b] In tests marked "sifted" all sand used was sifted through No. 30 and over No. 40 size.

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement. No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 6...	1:3	1.14	134-11	74.3	71.6	8.9	774	882	1,188	1,512	1,476
							936	864	1,152	1,566	1,458
							792	1,044	1,206	1,368	1,422
	Average						834	930	1,182	1,482	1,452
	1:4		134-12	75.2	74.6	8.3	576	864	936	1,044	1,134
							666	864	972	1,116	1,152
							576	756	864	990	1,206
	Average						606	828	924	1,050	1,164
	1:3 (sifted)		134-13	75.2	76.1	8.9	576	486	828	630	738
							504	630	756	558	828
							540	720	810	756	792
	Average						540	612	798	648	786
Sd. 7...	1:3	1.22	134-14	77.0	80.6	8.9	648	990	1,098	1,098	1,206
							720	954	1,044	972	1,278
							792	.....	1,206	1,044	1,260
	Average						720	972	1,116	1,038	1,148
	1:4		134-15	77.0	80.6	8.3	540	720	918	936	972
							342	702	990	1,026	918
							.....	738	882	918	972
	Average						441	720	930	960	954
	1:3 (sifted)		134-16	77.0	75.2	8.9	486	576	864	846	918
							468	.....	1,080	972	936
							468	612	954	828	828
	Average						474	594	966	882	894
Sd. 8...	1:3	1.16	134-17	77.0	75.2	8.9	576	1,134	1,044	1,260	1,296
							594	1,206	1,170	1,296	1,296
							432	1,026	1,080	1,206	.....
	Average						534	1,122	1,098	1,254	1,296
	1:4		134-18	77.0	70.7	8.3	468	1,008	1,026	1,224	954
							468	792	1,062	1,116	972
							414	810	918	1,170	972
	Average						450	870	1,002	1,170	966
	1:3 (sifted)		134-19	78.8	82.4	8.9	486	648	720	756	630
							468	576	792	864	648
							504	612	810	774	648
	Average						486	612	774	798	642
Sd. 9...	1:3	1.16	134-20	75.2	73.4	8.9	684	720	918	882	990
							684	792	1,062	972	1,008
							702	702	972	846	900
	Average						690	738	984	900	966
	1:4		134-21	77.0	77.0	8.3	648	612	792	864	738
							558	612	846	846	702
							540	630	756	936	684
	Average						582	618	798	882	708
	1:3 (sifted)		134-22	78.8	73.1	8.9	522	612	612	684	756
							558	612	702	702	684
							576	648	828	684	756
	Average						552	624	714	690	732

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Transverse strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 11..	1:3	1.13	135-4	78.8	82.4	8.9	864	1,152	1,260	1,188	.....
							774	1,044	1,332	1,296	.....
							738	1,116	1,188	1,332	.....
	Average						792	1,104	1,260	1,272	.....
	1:4		135-5	78.8	80.6	8.3	558	1,008	1,242	1,314	.....
							522	1,008	1,026	1,368	.....
							.....	918	1,188	1,314	.....
	Average						540	978	1,152	1,332	.....
Sd. 12..	1:3	1.12	135-6	79.5	77.0	8.9	648	954	1,368	1,350	.....
							900	1,008	1,368	1,404	.....
							810	882	1,224	1,386	.....
	Average						786	948	1,320	1,380	.....
	1:4		135-7	78.8	78.8	8.3	612	900	1,134	864	.....
							558	918	1,098	1,008	.....
							594	954	1,008	936	.....
	Average						588	924	1,080	936	.....
Sd. 13..	1:3	1.21	135-8	78.8	80.6	8.9	792	900	1,206	1,224	.....
							864	918	1,080	1,368	.....
							864	864	1,098	1,350	.....
	Average						840	894	1,128	1,314	.....
	1:4		135-9	78.8	77.0	8.3	666	.....	1,206	1,152	.....
							558	1,008	1,440	1,224	.....
							558	918	1,332	1,242	.....
	Average						594	963	1,326	1,206	.....
	1:3 (sifted)		135-14	80.6	84.2	8.3	558	900	990	918	.....
							612	720	1,116	972	.....
							.....	936	1,062	936	.....
	Average						585	852	1,056	942	.....
Sd. 14..	1:3	1.19	135-27	78.8	84.2	8.9	720	702	1,206	1,062	.....
							666	720	1,062	1,080	.....
							.....	792	1,116	990	.....
	Average						693	738	1,128	1,044	.....
	1:4		135- 6	81.4	82.4	8.3	594	666	972	900	.....
							576	702	918	936	.....
							630	612	918	846	.....
	Average						600	660	936	894	.....
	1:3 (sifted)		135-15	80.6	82.4	8.9	648	756	1,026	1,044	.....
							756	720	918	1,008	.....
							666	756	900	1,026	.....
	Average						690	744	948	1,026	.....
Sd. 15..	1:3	1.13	135-18	80.6	84.2	8.9	396	576	954	738	.....
							504	558	864	702	.....
							486	630	900	936	.....
	Average						462	588	906	792	.....
	1:4		135-19	77.0	68.0	8.3	360	468	396	756	.....
							324	504	486	756	.....
							288	450	360	720	.....
	Average						324	474	414	744	.....
	1:3 (sifted)		135-17	77.0	68.0	8.9	522	630	594	540	.....
							486	594	486	684	.....
							450	612	612	612	.....
	Average						486	612	564	612	.....

TABLE IXc.—*Transverse strength of the mortars of 22 sands*—Continued.

Register No.	Ratio of cement to sand.	Yield.	Cement No.	Temperature (° F.). Water.	Temperature (° F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Sd. 16..	1:3	1.20	135-22	78.8	75.2	8.9	846	1,080	1,044	972	.....
							882	1,152	1,206	1,008	.....
							846	1,134	1,242	972	.....
	Average	.....	.....	.....	.....	.....	858	1,122	1,164	984	.....
	1:4	.....	135-21	79.5	76.1	8.3	702	1,044	864	1,044	.....
							774	954	1,080	1,026	.....
							864	972	1,152	1,062	.....
	Average	.....	.....	.....	.....	.....	780	990	1,032	1,044	.....
	1:3 (sifted)	.....	135-20	77.0	73.4	8.3	774	954	756	864	.....
							576	864	1,008	936	.....
							828	864	1,044	882	.....
	Average	.....	.....	.....	.....	.....	726	894	936	894	.....
Sd. 17..	1:3	1.27	136-4	77.9	76.1	8.9	522	882	810	990	.....
							450	828	828	972	.....
							432	864	936	1,044	.....
	Average	.....	.....	.....	.....	.....	468	858	858	1,002	.....
	1:4	.....	136-3	78.8	80.6	8.3	468	756	828	972	.....
							432	648	828	972	.....
							396	720	792	954	.....
	Average	.....	.....	.....	.....	.....	432	708	816	966	.....
	1:3 (sifted)	.....	136-2	80.6	82.4	8.9	468	612	756	828	.....
							360	666	720	900	.....
							378	594	756	1,026	.....
	Average	.....	.....	.....	.....	.....	402	624	744	918	.....
Sd. 22..	1:3	1.11	.....	71	68	11.5	594	882	1,044	972	.....
							571	936	1,008	1,080	.....
							594	855	1,017	922	.....
	Average	.....	.....	.....	.....	.....	586	891	1,023	1,008	.....
	1:4	.....	.....	71	68	11.0	396	612	810	846	.....
							396	666	864	846	.....
							398	630	882	900	.....
	Average	.....	.....	.....	.....	.....	397	636	852	864	.....
	1:3 (sifted)	.....	.....	65	68	11.5	396	630	882	774	.....
							414	648	954	810	.....
							423	621	864	882	.....
	Average	.....	.....	.....	.....	.....	411	623	900	822	.....

TABLE X.—*Chemical analyses of silt contained in 17 sands, in 11 gravel screenings, and in 24 stone screenings*

[Values expressed in percentages.]

SILT CONTAINED IN SANDS.[a]

Register No.[b]	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3).	Manganese oxide (MnO).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Alkalies.		Water at 100° C.	Ignition loss.	
								Na_2O.	K_2O.		Total.	Carbon in organic matter.
Sd. 1	69.78	9.92	3.12	0.31	4.92	2.18	0.16	0.72	1.51	0.74	70.6	0.67
Sd. 3	46.46	10.06	5.14	.17	12.28	5.52	.09	.03	1.60	.55	18.23	2.00
Sd. 4	30.90	5.80	4.17	.11	18.06	11.36	.10	.37	.82	.50	28.04	.26
Sd. 6	27.98	8.90	1.36	.33	19.88	11.30	.22	1.04	.63	.66	27.90	.73
Sd. 7	31.18	6.20	4.84	.18	18.28	10.82	.17	.70	1.62	.57	25.83	.71
Sd. 8	31.63	5.99	3.81	.20	17.83	10.96	.33	1.65	.90	.14	56.75	.55
Sd. 9	28.94	14.69	1.27	.28	16.64	9.97	.10	.32	1.76	.79	25.51	.81
Sd. 10	37.40	6.77	7.99	.59	13.82	7.90	.10	1.76	1.52	.61	21.70	.53
Sd. 11	7.18	1.58	.68	.54	27.79	18.74	.89	.27	.71	.04	.....	.37
Sd. 12	5.54	1.59	.47	.11	28.56	18.43	.10	.86	.44	.08	43.94	.23
Sd. 13	39.52	10.59	2.87	1.30	17.06	4.66	.17	.86	1.36	.14	21.46	1.46
Sd. 14	57.30	8.03	.71	.18	12.53	4.58	.09	.87	.41	.25	15.27	.81
Sd. 16	47.78	5.87	3.27	.47	15.76	4.96	.14	1.04	1.06	.25	19.79	.96
Sd. 17	57.92	12.68	5.18	.20	7.60	3.04	.03	.03	2.19	.69	10.31	.58
Sd. 18	42.76	8.63	8.22	.74	12.50	7.02	.12	.19	1.30	.73	17.99	.....
Sd. 19	41.74	7.10	7.60	.61	14.58	6.15	.13	.71	1.73	.76	19.04	.42
Sd. 20	42.40	8.12	8.00	.50	12.78	6.82	.16	.86	1.68	.74	18.16	.....

SILT CONTAINED IN GRAVEL SCREENINGS.[c]

Gl. 1	51.90	9.10	2.04	0.30	11.56	1.96	0.17	1.51	0.94	1.61	18.95	4.09 4.11
Gl. 3	24.80	8.88	.96	.33	23.70	8.96	.04	.58	1.22	.51	29.87	1.08
Gl. 4	30.66	11.20	1.38	.74	18.66	9.13	.05	.55	1.53	.38	26.04	.67
Gl. 5	28.78	7.98	3.94	.46	20.68	9.07	.09	.67	1.61	.58	26.20	1.81
Gl. 6	43.90	9.77	3.25	.14	13.30	6.22	.03	.17	2.04	.57	20.57	.77
Gl. 7	29.24	6.16	3.08	.71	23.16	8.14	.17	.46	.90	.49	27.59	1.15
Gl. 8	27.30	8.75	1.61	.82	22.24	7.85	.35	.83	1.12	.42	28.58	2.11
Gl. 9	28.04	5.24	3.86	.22	25.28	6.02	.14	.41	.78	.51	29.59	1.67
Gl. 10	53.56	17.74	1.46	.37	8.36	3.42	.22	.59	1.91	.52	12.22	.88
Gl. 11	39.40	11.37	3.86	.40	15.32	6.43	.09	.20	2.15	.52	20.44	1.11
Gl. 12	41.68	12.02	4.09	.66	14.20	6.20	.06	.53	1.98	.63	18.09	.....

SILT CONTAINED IN STONE SCREENINGS.[d]

Se. 1[e]	22.56	2.66	2.97	.....	35.53	3.86	1.85	.....	.....	.....	28.60	0.29
Se. 2	19.89	8.40	.62	.....	36.88	1.81	.56	.....	.....	.....	34.04	.....
Se. 3	7.20	1.95	.56	0.37	47.50	1.42	.12	0.44	0.20	0.70	39.62	.34
Se. 4	6.05	.22	1.36	.....	47.50	3.70	1.01	.....	.....	.....	43.30	.....
Se. 5	13.40	2.60	.71	.50	45.48	.47	.19	.24	.40	.29	36.01	.21
Se. 7[f]	50.02	7.60	.81	.51	10.14	5.71	.14	.30	.65	.36	16.33	.84
Se. 8[g]	44.40	3.91	3.82	.....	22.53	1.82	3.52	.....	.....	.....	17.82	.27
Se. 9[h]	47.58	.69	1.97	.37	20.00	4.23	.12	.14	.40	.11	19.57	.30
Se. 10[i]	45.64	.98	2.27	.87	16.52	5.73	.12	.07	.23	.13	17.83	.19
Se. 11	20.84	6.51	1.71	.50	28.49	8.71	.99	.87	.42	.47	30.45	.31
Se. 12	7.16	3.40	2.70	1.24	46.08	1.28	.12	.17	.15	.38	37.66	.17
Se. 13	24.92	8.79	4.41	1.34	31.13	.17	.07	.46	1.26	.58	24.48	.20
Se. 14	9.02	3.10	3.42	1.10	45.00	.14	.14	.58	.06	.31	36.51	.16
Se. 15	25.72	8.96	3.50	.74	18.29	8.36	3.74	.42	5.17	.33	24.89	1.11
Se. 16	12.08	6.92	4.12	1.34	24.33	12.98	1.07	.54	1.47	.....	32.38	.25
Se. 17	65.90	16.94	2.72	.14	2.46	.52	.15	4.70	2.99	.66	3.08	.27
Se. 18	25.52	7.11	1.36	.22	18.58	13.92	.16	1.86	1.12	.51	29.91	.20
Se. 19[j]	15.68	4.61	.91	.45	22.21	17.05	.24	.03	1.67	.12	.....	.11
Se. 20[k]	14.28	3.31	2.05	.26	28.00	13.41	.22	.07	.88	.04	.....	.60
Se. 21	16.33	6.19	1.73	.40	26.24	13.04	.20	.10	.30	.19	.....	.26
Se. 22	7.66	1.43	1.86	.31	28.00	17.99	.08	.08	.35	.25	.....	.33
Se. 23	17.14	4.04	4.04	.43	35.80	4.21	.46	.16	.49	.35	.....	.34
Se. 24	10.18	3.01	.40	.36	29.18	14.53	.03	.36	1.11	.18	.....	.51
Se. 25	13.12	2.70	1.94	.48	39.22	4.87	.15	.32	.50	.20	.....	.51

[a] Not enough silt present in sands 2, 21, and 22 for analysis, and no chemical analysis was made of silt in sands 5 and 15.

[b] For details of field origin of samples see pp. 43–52 as to sands, pp. 80–86 as to gravels, and pp. 93–106 as to stone screenings.

[c] Not enough silt present in gravel 2 for analysis.

[d] No chemical analysis of silt in Se. 6 was made, as only a trace was present.

[e] Undetermined, 1.87.

[f] FeS_2, 3.65; ZnS, 3.79.

[g] Undetermined, 2.18.

[h] FeS_2, 1.57; ZnS, 3.20.

[i] FeS_2, 0.28; ZnS, 9.29.

[j] CO_2, 36.21.

[k] CO_2, 36.75.

TABLE XI.—*Uniformity coefficients of 22 sands and of 12 gravel screenings.*[a]

SANDS.

Register No.	Uniformity coefficient.	Voids.	Density.	Register No.	Uniformity coefficient.	Voids.	Density.
Sd. 12	7.576	33.5	0.738	Sd. 18	4.200	34.0	0.735
Sd. 11	6.382	36.0	.730	Sd. 4	3.969	28.0	.808
Sd. 20	5.625	28.0	.794	Sd. 6	2.978	31.6	.766
Sd. 1	5.465	32.5	.742	Sd. 10	2.785	31.6	.743
Sd. 3	5.436	36.1	.752	Sd. 5	2.733	34.6	.752
Sd. 16	5.105	29.7	.760	Sd. 22	2.700	36.4	.709
Sd. 8	4.957	30.7	.763	Sd. 17	2.552	34.5	.704
Sd. 9	4.909	31.4	.769	Sd. 7	2.333	31.6	.730
Sd. 13	4.879	28.9	.754	Sd. 2	2.322	34.9	.756
Sd. 19	4.450	26.9	.789	Sd. 21	1.706	40.9	.700
Sd. 14	4.273	31.9	.732	Sd. 15	1.692	40.5	.676

GRAVEL SCREENINGS.

Gl. 3	19.78	38.6	.....	Gl. 12	5.26	26.5	0.782
Gl. 6	13.07	27.9	0.772	Gl. 5	4.96	29.7	.756
Gl. 2	9.00	31.0	.763	Gl. 4	3.35	22.1	.....
Gl. 1	8.78	29.0	.771	Gl. 9	2.08	33.2	.804
Gl. 11	5.74	25.5	.796	Gl. 8	1.99	34.8	.741
Gl. 10	5.50	23.0	.783	Gl. 7	1.80	32.3	.783

[a] For details of field origin of sand samples see pp. 43–52; of gravel samples, pp. 80–86.

TABLE XII.—*Average physical properties of 22 sands, of 12 gravel screenings, and of 25 stone screenings, and their mortars.*[a]

SANDS AND THEIR MORTARS.

Register No.	Density.	Granulometric curve.	Measured voids (per cent).	Weight per cubic foot (pounds).	Strength of 1:3 mortar at 180 days (pounds per square inch).		
					Tensile.	Compressive.	Transverse.
1	2	3	4	5	6	7	8
Sd. 4	0.808	21	28.0	116.4	731	6,105	1,224
Sd. 20	.794	13	28.0	116.5	670	6,200	.....
Sd. 19	.789	17	26.9	119.9	773	6,719	.....
Sd. 9	.769	15	31.4	110.5	483	2,934	900
Sd. 6	.766	10	31.6	113.5	614	4,225	1,482
Sd. 8	.763	18	30.7	114.5	720	7,554	1,254
Sd. 16	.760	22	29.7	119.5	605	7,108	984
Sd. 2	.756	11	34.9	107.7	369	5,360	900
Sd. 13	.754	20	28.9	119.5	668	7,183	1,314
Sd. 3	.752	14	36.1	103.3	495	5,280	1,182
Sd. 5	.752	12	34.6	104.8	420	4,752	984
Sd. 10	.743	4	31.6	110.0	488	4,639	.....
Sd. 1	.742	5	32.5	109.3	415	3,677	1,056
Sd. 12	.738	19	35.5	106.5	601	6,125	1,380
Sd. 18	.735	6	34.0	106.5	550	3,667	.....
Sd. 14	.732	7	31.9	111.0	484	4,075	1,044
Sd. 7	.730	8	31.6	116.0	603	5,733	1,038
Sd. 11	.730	16	36.0	108.3	708	5,067	1,272
Sd. 22	.709	9	36.4	98.8	487	4,958	1,008
Sd. 17	.704	3	34.5	105.5	466	4,742	1,002
Sd. 21	.700	2	40.9	89.0	380	2,892	.....
Sd. 15	.676	1	40.5	95.5	331	2,633	792

[a] For details of field origin of sand samples see pp. 43–52; of gravel samples, pp. 80–86; of stone screenings, pp. 93–106.

TABLE XII.—*Average physical properties of 22 sands, of 12 gravel screenings, and of 25 stone screenings, and their mortars*—Continued.

GRAVEL SCREENINGS AND THEIR MORTARS.

Register No.	Density.	Granularmetric curve.	Measured voids (per cent).	Weight per cubic foot (pounds).	Strength of 1:3 mortar at 180 days (pounds per square inch).		
					Tensile.	Compressive.	Transverse.
1	2	3	4	5	6	7	8
Gl. 11	0.796	7	25.5	122.5	737	7,825	.....
Gl. 9	.791	11	30.7	117.8	654	8,567	.....
Gl. 12	.782	2	26.5	120.3	733	6,892	.....
Gl. 7	.774	12	32.8	113.4	690	6,325	.....
Gl. 6	.772	6	27.9	120.8	617	6,397	.....
Gl. 1	.771	8	29.0	115.0	601	7,460	.....
Gl. 2	.763	4	31.0	113.5	626	8,074	.....
Gl. 4	.759	1	30.9	117.1	703	5,570	.....
Gl. 5	.756	5	29.7	115.3	647	6,873	.....
Gl. 10	.749	3	27.9	118.9	546	5,433	.....
Gl. 8	.741	10	34.8	111.5	476	6,825	.....
Gl. 3	.....	9	38.6	102.6	426	4,654	.....

STONE SCREENINGS AND THEIR MORTARS.

Se. 8	0.774	16	34.6	105.5	793	6,307	1,374
Se. 10	.763	13	31.8	109.8	767	7,394	1,218
Se. 6	.760	21	33.1	109.5	750	8,048	1,326
Se. 14	.757	19	35.8	104.3	664	6,042	1,338
Se. 7	.756	14	36.1	102.7	677	5,279	1,206
Se. 4	.755	22	36.0	105.5	939	8,644	1,602
Se. 19	.753	3	39.3	102.5	790	5,459	1,560
Se. 25	.752	11	33.8	110.3	656	6,417	.....
Se. 9	.752	17	33.0	108.0	816	5,982	1,494
Se. 18	.746	12	39.0	103.8	623	6,221	1,380
Se. 5	.745	24	41.1	95.7	761	4,954	1,248
Se. 13	.743	9	38.2	102.2	807	5,394	1,356
Se. 1	.740	7	39.4	103.5	707	5,263	.....
Se. 16	.740	6	32.1	120.0	767	4,972	.....
Se. 23	.737	20	38.2	99.7	545	4,362	.....
Se. 3	.733	4	37.0	103.5	809	6,500	1,410
Se. 12	.733	5	35.1	105.3	717	6,193	1,446
Se. 15	.726	23	37.0	109.5	660	4,681	.....
Se. 2	.721	8	37.2	106.2	768	5,251	1,332
Se. 22	.719	10	37.5	106.3	924	7,382	.....
Se. 11	.709	2	42.1	95.5	543	3,757	918
Se. 24	.666	25	41.8	101.1	715	3,692	.....
Se. 21	.655	1	41.0	97.4	683	3,948	.....
Se. 17	.....	15	34.7	108.8	575	5,313	1,014
Se. 20	.....	18	35.2	108.5	505	4,998	.....

GRAVEL-SCREENINGS MORTARS.

ACKNOWLEDGMENT OF DONATIONS.

The 12 samples of gravel used in the investigations of gravel-screenings mortars reported in this bulletin were generously donated by the following firms and companies:

Buckeye Dredging Company, Columbus, Ohio.
Carey Construction Company, Cleveland, Ohio.
Wm. P. Carmichael, Attica, Ind.
Fleming & Co., Cincinnati, Ohio.
C. H. Little & Co., Detroit, Mich.
Loveland Sand and Gravel Company, Loveland, Ohio.
Moores-Cooney Company, Cincinnati, Ohio.
Mound City Gravel Company, St. Louis, Mo.
New Union Sand Company, St. Louis, Mo.
Ohio and Michigan Gravel and Sand Company, Toledo, Ohio.

METHOD OF COLLECTION.

The methods of collection and shipment were the same as those used with the samples of sand (p. 42).

The material in almost every sample represented the run of bank or bar, many samples having pebbles as large as 2 inches. For the purpose of making mortar only the material that passed a ¼-inch screen was used. A complete description of each sample of gravel, together with illustrations from photographs of the screenings (actual size), is given in the following pages. All the screenings were subjected to the usual physical determinations and were mixed with typical Portland cement to make mortar test pieces.

DESCRIPTIONS OF GRAVEL SCREENINGS.

Register No. Gl. 1.—A sample obtained from a recent deposit of river gravel at the Morsches Spur Bar in Meramec River was designated Gl. 1. A dipper dredge was operated over a space 1,200 feet long by 75 feet wide, transferring the material to scows or cars for delivery to St. Louis and other points. In handling the material by the dredge no attempt was made to wash out the silt.

Only 42 per cent of the sample received at the laboratories passed the ¼-inch screen, and no portion of these screenings passed the No. 80 sieve. As shown by the granularmetric analysis curve (fig. 15, p. 83), and the illustration (Pl. VIII, *C*, p. 54), the screenings are very uniformly graded. There is practically no fine material (smaller than the No. 80 sieve). The percentage of voids is 29; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.15 per cent, and the yield in 1:3 mortar is 1.16. The results of the strength tests on mortars made from these and 11 other gravel screenings are given in Table XIII (p. 89).

Register No. Gl. 2.—The sample designated Gl. 2 is a recent river gravel obtained from the Meramec River bar at Moselle, Mo. A clam-shell dredge operated over a space 4,000 feet long and 2,000 feet wide raises the material from the bottom of the river. The gravel is generally shipped to St. Louis, Mo.

About 58 per cent of the samples received at the laboratories passed the ¼-inch screen. As shown by the granularmetric analysis curve (fig. 14), these screenings are not far from uniform in grading and contain but a small portion of fine material, only 3 per cent passing the No. 80 sieve. The material is illustrated in Pl. IX, *A*. The percentage of voids is 31; the weight per cubic foot is 113.5 pounds; the amount of silt is 0.39 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from these gravel screenings are shown in Table XIII.

A *B* *C*

A. BAR GRAVEL SCREENINGS, MERAMEC RIVER, MOSELLE, MO. (SAMPLE 2).
B. BAR GRAVEL SCREENINGS, SCIOTO RIVER, COLUMBUS, OHIO (SAMPLE 3).
C. BANK GRAVEL SCREENINGS, LOVELAND, OHIO (SAMPLE 4).

Register No. Gl. 3.—The sample designated Gl. 3 is a mixture of limestone and granite, and the gravel is removed from a 500-foot bar in Scioto River, Columbus, Ohio, by means of an endless chain. It is dumped on scows, hauled to a suitable point, and placed in cars by a bucket and crane for shipment.

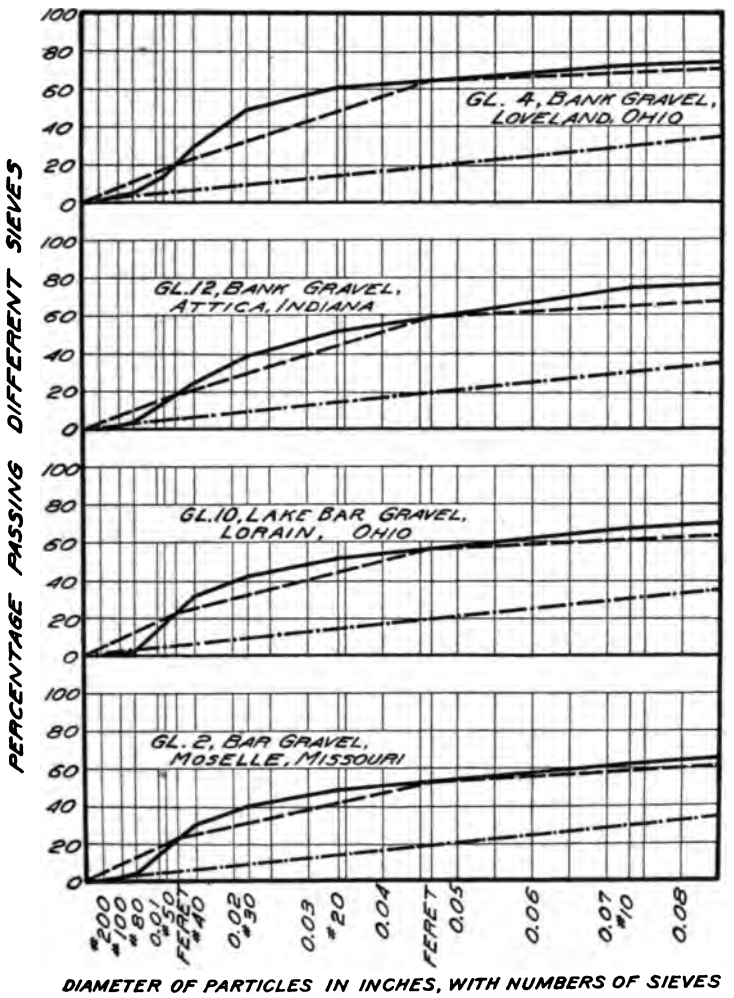


FIG. 14.—Granularmetric analysis curves for gravels 4, 12, 10, and 2. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

As received at the laboratories, this material was supposed to range from 1½- to ¼-inch material. On analysis it was discovered that 12 per cent of the material would pass the ¼-inch screen, and this portion was used in the mortar tests. As shown by the granularmetric analysis curve (fig. 16, p. 85), these screenings are very uniformly graded,

although 10 per cent passes the No. 80 sieve. The illustration (Pl. IX, *B*) also shows the uniformity in grading. The percentage of voids is 38.6; the weight per cubic foot is 102.6 pounds; and the amount of silt is 1.4 per cent. The results of the strength tests of mortars made from this gravel are shown in Table XIII (p. 89).

Register No. Gl. 4.—The sample designated Gl. 4 was obtained at Loveland, Ohio, from a gravel bank about 1,200 feet long and 60 feet wide, which was part of a glacial deposit. The material is excavated by a steam shovel and shipped to Cincinnati.

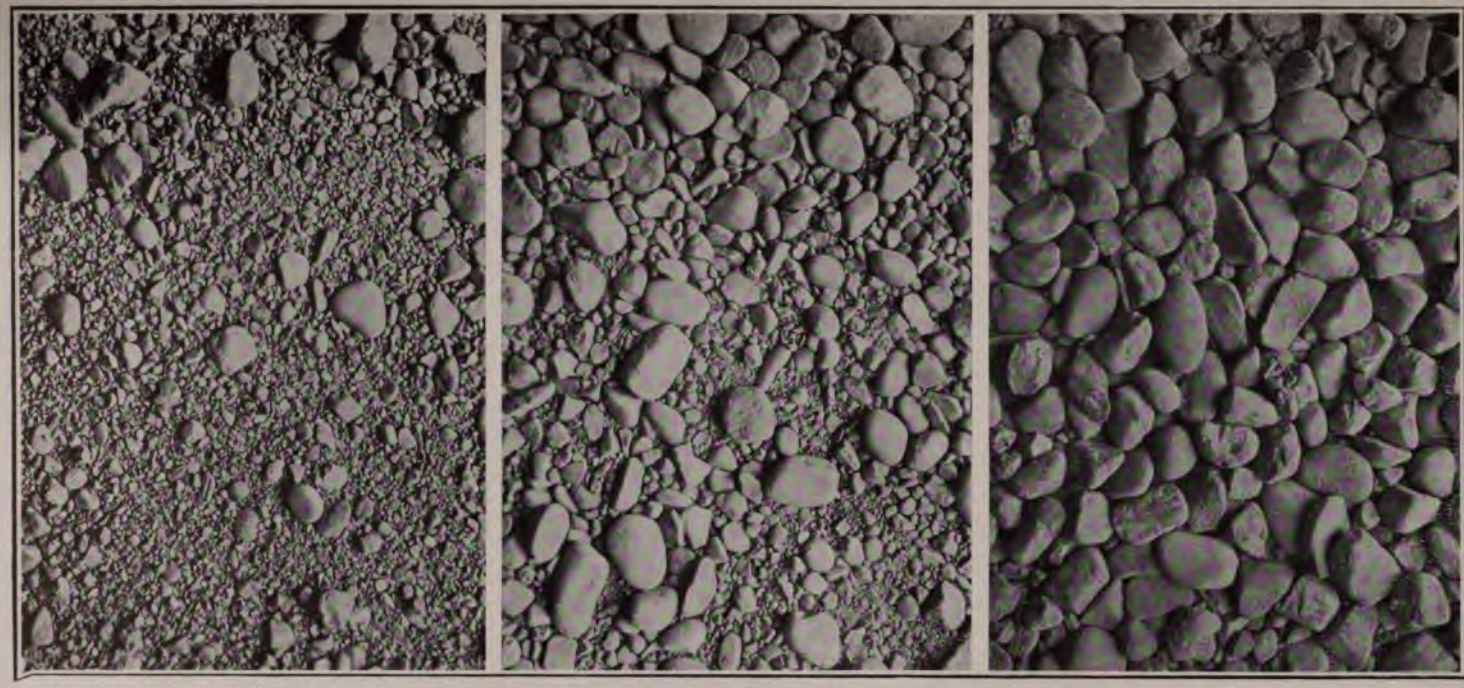
The gravel received at the laboratories was that portion which passed a 1-inch screen, and about one-third of this passed the ¼-inch screen. The granularmetric analysis curve (fig. 14, p. 81) shows that about 40 per cent of the ¼-inch screenings of this material passed the No. 20 sieve, and 5 per cent passed the No. 80 sieve. The percentage of voids is 30; the weight per cubic foot is 117.1 pounds; the amount of silt is 2.67 per cent, and the yield in 1:3 mortar is 1.15. The results of the strength tests of mortars made from this gravel are shown in Table XIII. The screenings are illustrated in Pl. IX, *C*.

Register No. Gl. 5.—The sample designated Gl. 5 is obtained from a deposit of river alluvium and glacial material spread over about 10 acres near Carthage, Ohio. This material was excavated by pick and shovel, and shipped to Cincinnati and vicinity. It contains but a small proportion of coarse particles, and it is generally passed over a ¼-inch screen and the screenings used as sand.

Of the sample received at the laboratories 81 per cent passed the ¼-inch screen. As shown by the granularmetric analysis curve (fig. 15), only 2 per cent of this material passed the No. 50 sieve, and the remainder of the grading followed the general direction of the uniform-grade line. The percentage of voids is 29.7; the weight per cubic foot is 115.3 pounds; the amount of silt is 0.4 per cent, and the yield in 1:3 mortar is 1.15. The results of the strength tests of mortars made from these screenings are shown in Table XIII (p. 89). This sample is illustrated in Pl. X, *A*. The uniform grading of the material and the absence of anything resembling dust or very fine grains are evident.

Register No. Gl. 6.—Sample designated Gl. 6 was obtained from an alluvial and glacial deposit at Ludlow, Ky., the area worked being 600 feet long and 70 feet wide. The gravel is a mixture of natural, ungraded bank gravel and sand, with particles as large as 1¼ inches.

The sample received at the laboratories all passed the ¼-inch screen, and, as shown by the granularmetric analysis curve (fig. 15), 31 per cent passed the No. 30 sieve. The percentage of voids is 27.9; the weight per cubic foot is 120.8 pounds; the amount of silt



A *B* *C*

A. BANK GRAVEL SCREENINGS, CARTHAGE, OHIO (SAMPLE 5).
B. BANK GRAVEL SCREENINGS LUDLOW, KY. (SAMPLE 6).
C. BANK GRAVEL SCREENINGS, CHILSON, MICH. (SAMPLE 7).

is 2.85 per cent, and the yield in 1:3 mortar is 1.22. The results of the strength tests of mortar made from these screenings are shown in Table XIII. This sample is illustrated in Pl. X, *B*.

Register No. Gl. 7.—One sample, designated Gl. 7, was obtained from a glacial deposit at Chilson, Mich., and was excavated by steam shovel from a pit 530 feet long and 30 feet wide. The run-of-bank

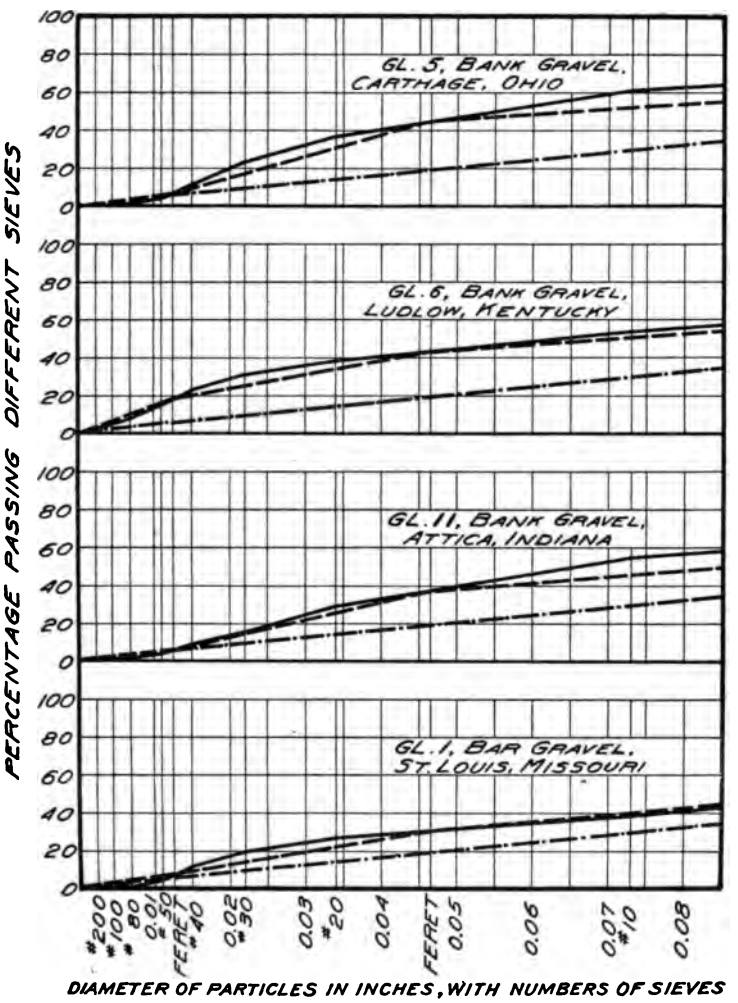


FIG. 15.—Granularmetric analysis curves for gravels 5, 6, 11, and 1. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

gravel could not be procured, inasmuch as all the material was sized by a series of screens. The sample shipped to the laboratories was designated as a No. 2 washed gravel, and comprised particles between three-eighths and 1¼ inches. The graded material is used in the vicinity of Toledo, Ohio.

The commercial sizing of the gravel is not perfect; of the sample received at the laboratories about 22 per cent passed the ¼-inch screen, and scarcely any of it passed the No. 10 sieve. The screenings give a very peculiar granularmetric analysis curve (fig. 16), starting at about 0 at the No. 10 sieve and going to 100 at the ¼-inch screen. They are practically one-size material between the ¼-inch and the No. 10. The percentage of voids is 32.8; the weight per cubic foot is 115.2 pounds; the amount of silt is 0.2 per cent, and the yield in 1:3 mortar is 1.10. The results of the strength tests of mortars made from these screenings are shown in Table XIII. These screenings are illustrated in Pl. X, *C*. It is very evident from the photograph that this material is not uniformly graded, and also that there are practically no very fine grains.

Register No. Gl. 8.—The sample designated Gl. 8 is another grade of the material just described (Gl. 7). Commercially, it is regarded as a ⅛-inch to ⅜-inch size, and the granularmetric analysis at the laboratories (fig. 16) shows that this is very nearly the case.

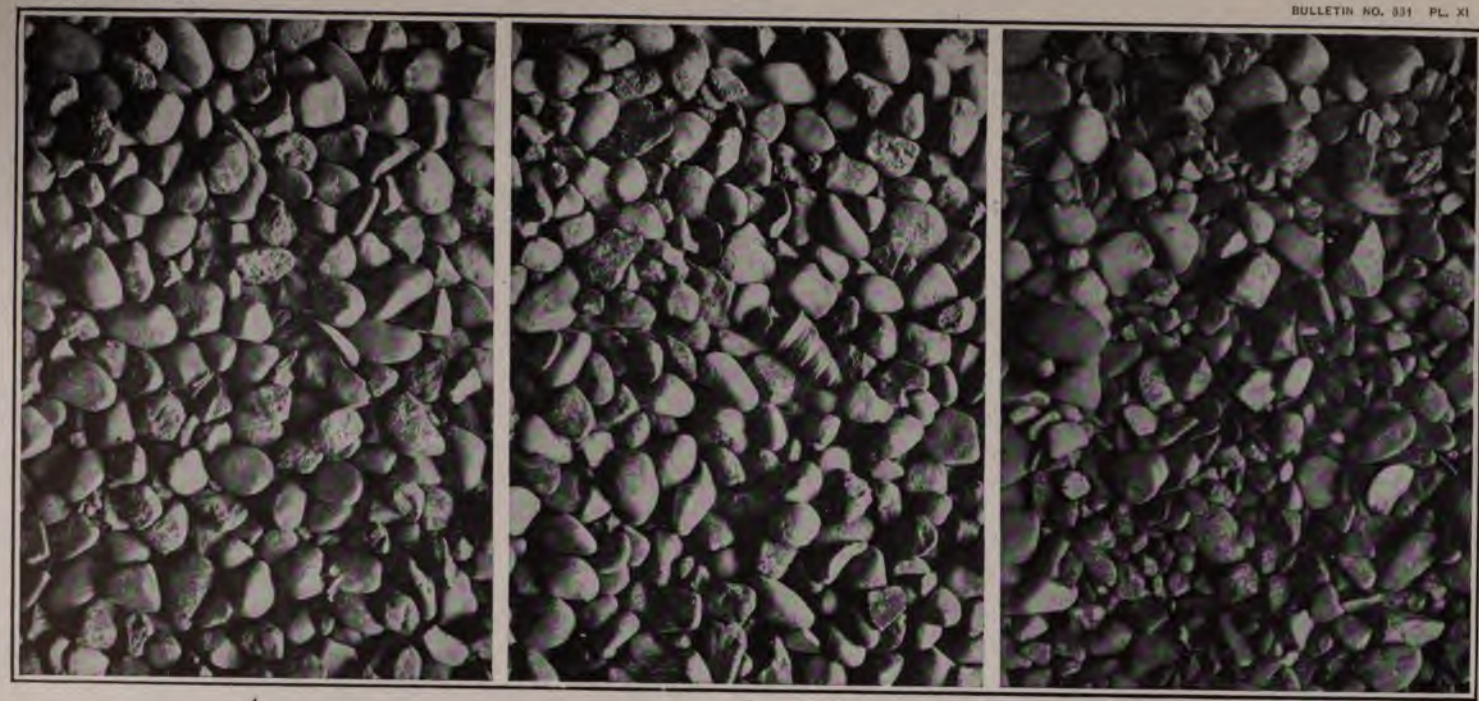
Of the sample received 48 per cent was retained on the ¼-inch screen and 98 per cent on the No. 10 sieve. This material is therefore practically a one-size material. The percentage of voids is 34.8; the weight per cubic foot is 111.5 pounds; and the amount of silt is 0.2 per cent; the yield of 1:3 mortar was not determined. The results of the strength tests of mortars are shown in Table XIII. The material is illustrated in Pl. XI, *A*.

Register No. Gl. 9.—The sample designated Gl. 9 was obtained from the shore of St. Clair River near Amherstburg, Ontario. It was pumped into scows by means of a centrifugal pump and taken to Detroit, Mich. The sample shipped to the laboratories consisted of screenings of approximately one size sifted out of the material excavated.

The granularmetric analysis (fig. 16) shows that practically all the material was retained by the No. 10 sieve. The percentage of voids is 30.7; the weight per cubic foot is 117.8 pounds; the amount of silt is 0.7 per cent, and the yield in 1:3 mortar is 1.10. The results of strength tests of mortars made from this material are shown in Table XIII. The appearance of the material may be seen in Pl. XI, *B*.

Register No. Gl. 10.—The sample designated Gl. 10 was obtained from a "wash" on the shore of Lake Erie, near Lorain, Ohio. The extent of the deposit is indefinite. The material was handled by pick and shovel and shipped to Cleveland. In commercial form this product ranges from 3-inch pebbles down to the finest sands.

Of the sample shipped to the laboratories 62 per cent passed the ¼-inch screen. As indicated by the granularmetric analysis curve (fig. 14, p. 81), about 50 per cent of the screenings lie between the



A *B* *C*

A. BANK GRAVEL SCREENINGS, CHILSON, MICH. (SAMPLE 8).
B. ST. CLAIR RIVER GRAVEL SCREENINGS, AMHERSTBURG, ONTARIO (SAMPLE 9).
C. LAKE ERIE GRAVEL SCREENINGS, LORAIN, OHIO (SAMPLE 10).

No. 20 and the No. 80 sieves. The gravel is illustrated in Pl. XI, *C*. The percentage of voids is 27.9; the weight per cubic foot is 118.9 pounds; the amount of silt is 0.4 per cent, and the yield in 1:3 mortar is 1.19. The results of the strength tests on mortars made from these screenings are shown in Table XIII.

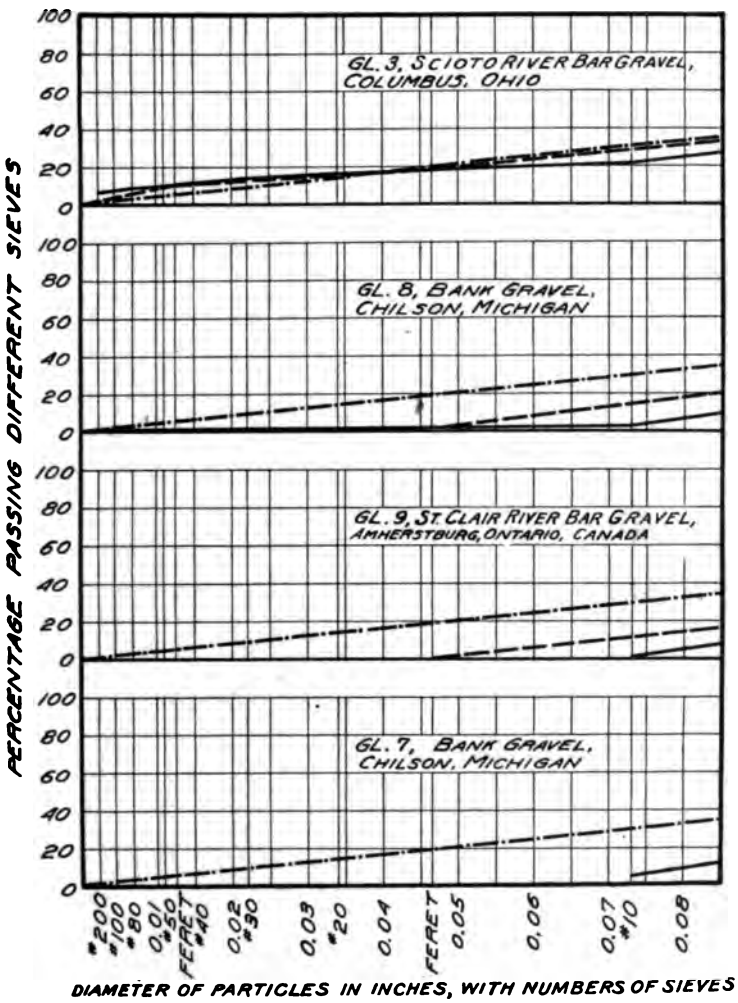


FIG. 16.—Granularmetric analysis curves for gravels 3, 8, 9, and 7. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Register No. Gl. 11.—Sample designated Gl. 11 was obtained at Attica, Ind., from the deposit described under "Sd. 18" (p. 49). Of the sample shipped to the laboratories, 40 per cent passed the ¼-inch screen, and only 28 per cent passed the No. 20 sieve (fig. 15, p. 83). The percentage of voids is 25.5; the weight per cubic foot is

122.5 pounds; the amount of silt is 0.3 per cent; and the yield in 1.3 mortar is 1.20. The results of the strength tests of mortars made from these screenings are shown in Table XIII. The uniform grading of the particles is apparent at a glance (Pl. XII, *A*).

Register No. Gl. 12.—A second sample from Attica, Ind., designated Gl. 12, is a bank gravel from the same locality as Gl. 11. Of the sample shipped to the laboratories 86 per cent passed the ¼-inch screen, and 50 per cent passed the No. 20 sieve (fig. 14, p. 81). The percentage of voids is 26.5; the weight per cubic foot is 120.3 pounds; the amount of silt is 0.5 per cent, and the yield in 1:3 mortar is 1.18. The results of the strength tests of mortars made from these screenings are shown in Table XIII. The illustration of this material (Pl. XII, *B*) shows the comparatively uniform grading of the particles. There is a small amount of very fine material present and a rather large amount of large grains.

PHYSICAL TESTS OF GRAVEL SCREENINGS.

Method.—When a sample of gravel is received at the laboratories it is spread on a concrete floor and turned at intervals until thoroughly air dried. It is then passed over a ¼-inch screen to separate the coarser material. Great care is taken so that no part of the fine material shall be lost. The percentage of the original shipment that passes the ¼-inch screen is recorded. The screenings are used in the mortar tests and the residue above the ¼-inch size is discarded.

The screenings (all of which have passed the ¼-inch screen) are submitted to tests for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, and percentage of moisture. These results are given in Table VIII (p. 59). The percentage and chemical composition of silt are given [illegible] X (p. 77).

Granularmetric analysis.—The set of sieves for th[illegible]larmetric analysis consists of Nos. 10, 20, 30, 40, 50, 80, 100, and 200. It was found that great care had to be taken in order to get a representative sample of each lot, on account of the tendency of the fine material to work to the bottom of the mass.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 14, 15, and 16, the ordinate at any sieve being the total percentage that passes that sieve. These curves are arranged in the order of the segment included between the granularmetric analysis curve, shown in full line, and the uniform-grade line, shown by dots and dashes. The sample which departs farthest from the uniform grading is Gl. 4 (at the top of fig. 14, p. 81), and the curves gradually approach the uniform-grade line until Gl. 3 (at the top of fig. 16, p. 85) is reached. This sample drops slightly below the uniform-grade line at the No. 10 sieve, and is slightly above it at the other

A *B* *C*

A. BANK GRAVEL SCREENINGS, ATTICA, IND. (SAMPLE 11).
B. BANK GRAVEL SCREENINGS, ATTICA, IND. (SAMPLE 12).
C. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 1).

sieves, but very nearly coincides throughout the entire length. The three samples following Gl. 3 in fig. 16 are rather coarse and contain practically no material under the No. 10 sieve. The granularmetric analysis curves for these samples consist practically of a short line starting at 0 at the No. 10 sieve and inclining toward 100 at the ¼-inch screen. In these charts the mechanical analysis curves by means of Feret's two-sieve method are shown in broken lines.

Comparison between measured and computed voids.—In the determination of the percentage of voids and weight per cubic foot, three independent determinations were made.

In order to afford a basis of comparison between the measured voids and the computed voids the latter were computed by means of the specific gravity and the weight per cubic foot, as explained under "Physical tests of sands" (p. 55). The measured and computed voids and the differences between them are given in Table VIII (p. 59). In columns 14 and 15 are also given the differences between the values, the difference in each case being marked under the method giving the higher value. The averages of the differences are shown in the line marked "Average." The difference between them is zero, showing that in this case the results by each method were of equal value.

Uniformity coefficient.—The uniformity coefficients of the gravel screenings studied in these investigations are arranged progressively in decreasing order in Table XI (p. 78). For convenience of comparison the percentage of voids and the density for each sample are also given in the table.

PHYSICAL TESTS OF GRAVEL-SCREENINGS MORTARS.

Method.—Each of the gravel screenings described in the preceding pages was mixed with typical Portland cement to form mortar of different proportions, and this mortar was made into test pieces for tensile and compressive tests. Proportions of 1:3 and 1:4 are used in every case.

Since it was found impossible to obtain sufficient material of one size, no one-size mortar test pieces were made. Test pieces were made of each sample of gravel screenings for each kind of stress, and three pieces were tested at each of the five ages—7, 28, 90, 180, and 360 days.

The results of the strength tests on these mortars, including the register number, the yield at the 1:3 ratio, the register number of the corresponding typical Portland cement test pieces, the temperature of the water and of the air at the time of molding, the percentage of water used for normal consistency, and the breaking strength (in pounds per square inch) at different ages are given in Table XIII (p. 89). Table VIII summarizes data respecting the field origin and

nature of each sample of gravel, and the average physical properties are given in Table XII (p. 78).

The results of the strength tests on neat-cement test pieces made from the same cement used in the mortar are given in Table VII (p. 36) and are plotted in figs. 6 (p. 35), 7 (p. 39), and 8 (p. 40). The corresponding typical Portland cement numbers are given in Table XIII, so that the strength of the mortar may be compared with the strength of the neat cement used in the mortar.

Tensile strength.—The results of the tensile tests are given in Table XIII*a* (p. 89). The results are arranged in groups of three, in the same way as for the sand mortars, and the average of each group is shown in the line marked "Average." The results given in the table are the total breaking loads on 1-inch briquets.

The lack of uniformity in the increase in strength is probably due to physical differences in the gravel screenings. In general, the tensile strength of both mortars seems to decrease with the increase in the percentage of voids.

Compressive strength.—The results of the compressive tests are given in Table XIIIb (p. 91). The values in this table are in pounds per square inch, and are obtained by dividing the total breaking load by the area of the cross section of the 2-inch cube. Considering these tests in the order of the percentage of voids, it can be seen that the strength appears to decrease with the increase in the percentage of voids.

Summary of gravel-mortar tests.—A great deal of irregularity can be expected in the testing of gravel-screenings mortar test pieces. This is due to the fact that the operator finds it difficult to obtain a thoroughly uniform mass, especially when the material is composed of coarse grains of approximately one size. In the latter case it invariably happens that the cement and gravel screenings occur in the test pieces in streaks. In many cases the cement accumulates at one side of the neck of the briquet, and the active section is reduced so that the briquet gives eccentric results when tested.

Density.—The density of mortar made from each sample of gravel screenings was determined in order to ascertain its relation to the other physical properties and to see if the strength of the mortar can be approximately foretold by the density.

The density of 1:3 mortar and the relation between the density and other physical properties of the screenings and mortars are given in Table XII (p. 79). In column 1 are given the register numbers of the gravel screenings used in the mortars whose densities are given in column 2. The densities are arranged in order, with the largest value at the top. For purposes of comparison, the number of the granularmetric analysis curve for each gravel is given in column 3. These numbers start with No. 1 for Gl. 4 (at the top of fig. 14, p. 81)

and end with No. 12 for Gl. 7 (at the bottom of fig. 16, p. 85). The percentage of voids, weight per cubic foot, and tensile and compressive strengths of the corresponding mortars at 180 days are given in columns 4–8.

TABLE XIIIa.—*Tensile strength of the mortars of 12 gravel screenings.*

Register No.[a]	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days
Gl. 1	1:3	1.16	79-1	66.2	67.6	9.1	308	565	540	595	525
							326	550	580	632	491
							330	535	590	575	502
	Average						321	550	570	601	506
	1:4		79-6	65.8	64.1	8.4	395	509	438	509	418
							416	492	493	508	407
							380	467	490	520	400
	Average						397	489	474	512	408
Gl. 2	1:3	1.14	79-2	63.5	59.0	9.1	365	528	600	595	460
							380	503	643	652	485
							353	566	611	630	522
	Average						366	532	618	626	489
	1:4		79-7	66.2	66.5	8.4	371	485	522	485	492
							390	452	475	530	476
							400	456	481	500	480
	Average						387	464	493	505	483
Gl. 3	1:3		79-36	68.0	68.9	8.9	311	457	459	432	510
							317	469	477	420	504
							350	440	470	425	482
	Average						326	455	469	426	499
	1:4		79-36	68.0	68.9	8.3	338	388	452	363	465
							310	412	430	365	450
							305	380	440	369	427
	Average						318	393	441	366	447
Gl. 4	1:3	1.15	79-33	69.8	63.0	8.9	457	612	700	697	733
							435	590	750	712	698
							432	580	767	700	709
	Average						441	594	739	703	713
	1:4		79-33	69.8	63.0	8.3	422	545	610	620	692
							410	542	650	652	652
							430	485	627	.....	658
	Average						421	524	629	636	667
Gl. 5	1:3	1.15	79-30	70.7	72.5	8.9	592	600	730	623	665
							539	605	710	627	735
							537	626	755	690	722
	Average						556	610	732	647	707
	1:4		79-30	70.7	72.5	8.3	445	547	670	600	638
							458	530	660	594	654
							420	531	615	578	656
	Average						441	536	648	591	649
Gl. 6	1:3	1.22	79-38	69.8	68.0	8.9	155	560	640	577	642
							480	600	630	654	682
							442	610	600	620	646
	Average						459	590	623	617	657
	1:4		79-38	69.8	68.0	8.3	394	478	500	510	586
							399	502	540	575	572
							385	510	.....	591	590
	Average						393	497	520	559	583

[a] For details of field origin of samples of gravel screenings see pp. 80–86.

TABLE XIIIa.—*Tensile strength of the mortars of 12 gravel screenings*—Continued.

Register No.	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent.)	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 7	1:3	1.10	79-49	68.0	67.1	8.9	563	590	635	718	697
							600	625	670	663	726
							620	590	650	.....	724
	Average						594	602	652	690	716
	1:4		79-40	68.0	67.1	8.3	399	380	486	505	545
							410	420	460	602	535
							370	423	.....	.....	560
	Average						393	408	473	553	547
Gl. 8	1:3		79-51	69.8	62.0	8.9	420	488	555	563	505
							475	502	585	438	511
							.....	.....	.....	426	502
	Average						448	495	570	476	506
	1:4		79-51	69.8	62.0	8.3	208	290	415	422	465
							255	320	450	403	475
							200	.....	.....	437	432
	Average						221	305	433	421	457
Gl. 9	1:3	1.10	79-55	68.9	68.0	8.9	529	545	600	663	704
							480	586	605	630	710
							490	585	560	670	682
	Average						500	572	589	654	699
	1:4		79-55	68.9	68.0	8.3	513	476	540	546	556
							490	495	490	560	570
							486	520	.....	561	547
	Average						496	497	515	556	558
Gl. 10	1:3	1.19	79-57	7.16	6.42	8.9	336	465	.....	526	593
							340	470	550	585	586
							315	475	568	527	616
	Average						330	470	559	546	598
	1:4		79-57	7.16	64.2	8.3	227	352	447	458	510
							250	363	437	482	501
							251	378	399	491	487
	Average						243	364	428	477	499
Gl. 11	1:3	1.20	133-23	69.8	64.0	8.9	492	625	730	745	768
							500	615	765	730	758
							455	640	.....	740	793
	Average						482	627	748	737	773
	1:4		133-23	69.8	64.0	8.3	392	484	540	575	626
							415	475	500	510	612
							.....	447	535	570	630
	Average						403	469	525	552	623
Gl. 12	1:3	1.18	133-28	68.0	66.2	8.9	485	600	690	710	812
							490	587	641	764	798
							487	615	.....	726	824
	Average						487	601	666	733	811
	1:4		133-28	68.0	66.2	8.3	398	536	569	665	604
							360	545	527	645	628
							388	531	545	594	660
	Average						382	535	547	635	631

TABLE XIIIb.—*Compressive strength of the mortars of 12 gravel screenings.*

Register No.[a]	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.)		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 1	1:3	1.16	79-1	69.0	68.7	9.1	3425	5216	6525	1608	8185
							3362	5737	6555	7408	7340
							3237	5650	7325	7363	7920
	Average						3341	5532	6802	7466	7185
	1:4		79-9	71.2	68.0	8.4	1362	2912	3930	4908	4000
							1735	3300	3750	5163	3663
							1592	3085	4075	4900	4075
	Average						1563	3099	3918	4990	3913
Gl. 2	1:3	1.14	79-2	74.8	66.2	9.1	4400	6270	7683	7513	9660
							4507	6107	7468	8360	9200
							4435	5902	7000	8350	8940
	Average						4447	6093	7384	8074	9267
	1:4		79-10	70.7	52.0	8.4	1845	3375	4530	5023	5300
							1852	3550	4708	5263	4925
							2000	3517	5000	4750	4975
	Average						1899	3481	4746	5012	5067
Gl. 3	1:3		79-36	68.0	70.7	8.9	1925	3400	3763	4725	4825
							1913	3075	3553	4725	4750
							1958	3250	4193	4512	4650
	Average						1932	3242	3970	4654	4742
	1:4		79-36	68.0	70.7	8.3	1460	2518	2848	3438	3875
							1450	2500	3163	3400	4175
							1358	2830	2920	3012	4075
	Average						1423	2616	2977	3233	4042
Gl. 4	1:3	1.15	79-28	70.7	64.4	8.9	2,455	3,975	5,890	5,612	7,425
							2.350	3,725	6,025	5,800	7,050
							2,388	3,987	6,380	5,300	7,100
	Average						2,398	3,896	6,098	5,570	7,192
	1:4		79-28	70.7	64.4	8.3	1,488	2,500	4,675	4,500	4,675
							1,368	2,942	4,688	4,800	4,600
							1,463	2,787	4,403	5,025	4,450
	Average						1,440	2,743	4,589	4,775	4,575
Gl. 5	1:3	1.15	79-25	68.9	69.8	8.9	2,957	4,515	5,975	7,163	7,450
							3,375	4,713	6,050	6,583	7,850
							3,250	4,425	6,138	.....	7,700
	Average						3,194	4,551	6,054	6,873	7,667
	1:4		79-25	68.9	69.8	8.3	2,300	3,520	4,325	5,970	5,250
							2,250	3,473	4,050	5,515	5,800
							2,337	3,268	4,163	5,760	5,850
	Average						2,296	3,420	4,179	5,748	5,633
Gl. 6	1:3	1.22	79-38	68.0	68.0	8.9	3,025	4,040	7,250	6,463	7,175
							3,133	4,415	5,815	6,375	6,725
							3,160	4,258	7,013	6,352	7,175
	Average						3,106	4,238	7,026	6,397	7,025
	1:4		79-38	68.0	68.0	8.3	2,320	3,988	4.875	.....	6,500
							2,500	3,833	5,110	5,705	6,550
							2,558	3,800	5,115	6,038	6,725
	Average						2,459	3,874	5,033	5,871	6,592
Gl. 7	1:3	1.10	79-49	69.8	68.0	8.9	3,825	4,438	7,295	5,700	6,425
							3,875	4,220	6,970	.....	6,162
							.....	.....	.....	6,950	6,550
	Average						3,850	4,329	7,133	6,325	6,379
	1:4		79-40	69.8	68.0	8.3	1,533	3,523	3,557	1,875	4,325
							1,475	3,338	.....	.....	4,250
							.....	3,000	3,975	1,500	4,450
	Average						1,504	3,287	3,766	1,687	4,342

[a] For details of field origin of samples of gravel screenings, see pp. 80–86.

TABLE XIIIb.—*Compressive strength of the mortars of 12 gravel screenings*—Continued.

Register No.	Ratio of cement to gravel.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Gl. 8	1:3		79-51	69.8	69.8	8.9	2,638	2,650	3,250	6,550	5,375
							2.225	2,388	3,162	7,100	5,050
							2,538	.....	.....	.....	4,100
	Average						2,484	2,519	3,206	6,825	4,842
	1:4		79-51	69.8	69.8	8.3	763	1,310	3,725	2,050	2,125
							638	1,500	3,800	2,100	2,175
							663	.....	.....	.....	2,525
	Average						688	1,405	3,762	2,075	2,275
Gl. 9	1:3	1.10	79-55	69.8	68.0	8.9	4,595	5,550	6,288	8,200	8,900
							4,475	5,000	6,438	8,725	9,062
							4,538	5,488	5,810	8,775	9,400
	Average						4,536	5,346	6,179	8,567	9,121
	1:4		79-55	69.8	68.0	8.3	4,175	5,145	.....	6,600	7,375
							4,025	5,163	5,695	6,375	7,625
							3,950	5,345	5,863	6,050	7,300
	Average						4,050	5,218	5,779	6,342	7,433
Gl. 10	1:3	1.19	79-57	69.8	64.2	8.9	2,318	4,050	4,570	5,300	4,950
							2,288	4,388	4,763	5,475	5,125
							.....	4,000	4,325	5,525	4,937
	Average						2,303	4,146	4,553	5,433	5,004
	1:4		79-57	69.8	64.2	8.3	1,370	1,888	2,608	3,225	3,037
							1,450	1,775	2,582	3,350	3,075
							1,413	.....	2,680	3,250	3,075
	Average						1,411	1,832	2,607	3,275	3,062
Gl. 11	1:3	1.20	133-23	68.9	68.0	8.9	4,630	6,365	6,225	9,000	8,675
							4,638	6,238	6,375	7,300	8,975
							.....	6,200	6,600	7,175	8,800
	Average						4,634	6,268	6,400	7,825	8,817
	1:4		133-23	68.9	68.0	8.3	2,595	3,938	.....	4,450	4,975
							2,363	3,688	4,425	4,400	4,325
							2,550	3,775	3,925	4,750	4,300
	Average						2,503	3,800	4,175	4,533	4,533
Gl. 12	1:3	1.18	133-28	68.9	74.3	8.9	3,623	5,225	5,550	7,050	8,050
							3,575	5,200	4,925	6,850	7,425
							3,573	.....	5,275	6,775	8,225
	Average						3,590	5,212	5,250	6,892	7,900
	1:4		133-28	68.9	74.3	8.3	2,790	4,050	4,550	4,950	6,050
							2,675	3,775	4,650	5,250	6,250
							2,685	3,700	.....	4,725	6,150
	Average						2,717	3,842	4,600	4,975	6,150

STONE-SCREENINGS MORTARS.

ACKNOWLEDGMENT OF DONATIONS.

In the investigations reported in this bulletin, 25 samples of stone screenings were used. They were generously donated by the following firms and companies:

Bambrick-Bates Construction Company, St. Louis, Mo.
Buckeye Dredging Company, Columbus, Ohio.
Bull Frog Mining Company, Joplin, Mo.
Casparis Stone Company, Casparis, Ohio.
Chicago Crushed Stone Company, Chicago, Ill.

Fruin-Bambrick Company, St. Louis, Mo.
Glencoe Lime and Cement Company, St. Louis, Mo.
Granby Zinc and Mining Company, Joplin, Mo.
Hillsboro Stone Company, Hillsboro, Ohio.
Horton Stone and Milling Company, Springfield, Mo.
McLaughlin-Mateer Company, Kankakee, Ill.
McTernan & Halpin Construction Company, Kansas City, Mo.
Ozark Red Granite Company, Graniteville, Mo.
Perkinson Brothers, St. Louis, Mo.
Rucker Stone Company, Greenfield, Ohio.
St. Joseph Lead Company, Bonne Terre, Mo.
St. Joseph Street Construction Company, St. Louis, Mo.
Samuels & Holmes, Kansas City, Mo.
Sibley Quarry Company, Sibley, Mich.
Toledo Stone and Glass Sand Company, Sylvania, Ohio.

METHOD OF COLLECTION.

These samples were collected and shipped to the laboratories in the manner described for sands (p. 42). All the screenings were subjected to the usual physical determinations and were mixed with cement to make mortar test pieces. A complete description of each sample of stone screenings, together with illustrations from photographs (actual size) and the detailed results of tests, is given in the following pages.

DESCRIPTIONS OF STONE SCREENINGS.

Register No. Se. 1.—The sample designated Se. 1 was obtained from a quarry at St. Louis, Mo. This stone is geologically known as the St. Louis limestone, of the Mississippian series. It was blasted with black powder for dimension stones, and with dynamite for crusher stone, and is worked and handled by means of steam drills and derricks. The quarry covers a space 400 by 200 feet to a depth of 225 feet. The sample here described was taken from the deepest bed in the quarry, and is a very fine-grained, dense rock. The upper beds in the same quarry vary in texture from coarse to medium.

Of the crusher run, as received at the laboratories, 40 per cent passed the ¼-inch screen, and of this portion 40 per cent passed the No. 20 sieve and 10 per cent the No. 80 sieve (fig. 18, p. 96). The percentage of voids is 39.4; the weight per cubic foot is 103.5 pounds; the amount of silt is 4.9 per cent, and the yield in 1:3 mortar is 1.04 The results of the strength tests of mortars made from these screenings are shown in Table XIV (pp. 109–124). An illustration of the screenings is shown in Pl. XII, *C* (p. 86).

Register No. Se. 2.—A sample obtained from the upper bed of the formation in the quarry from which sample Se. 1 was taken was designated Se. 2.

Of the entire run as received at the laboratories 43 per cent passed the ¼-inch screen, and of this portion 40 per cent passed the No. 20 sieve and 10 per cent the No. 80 sieve (fig. 18, p. 96). The percentage of voids is 37.2; the weight per cubic foot is 106.2 pounds; the amount of silt is 5.4 per cent, and the yield in 1:3 mortar is 1.1. The results of the strength tests of mortars made from these screen-

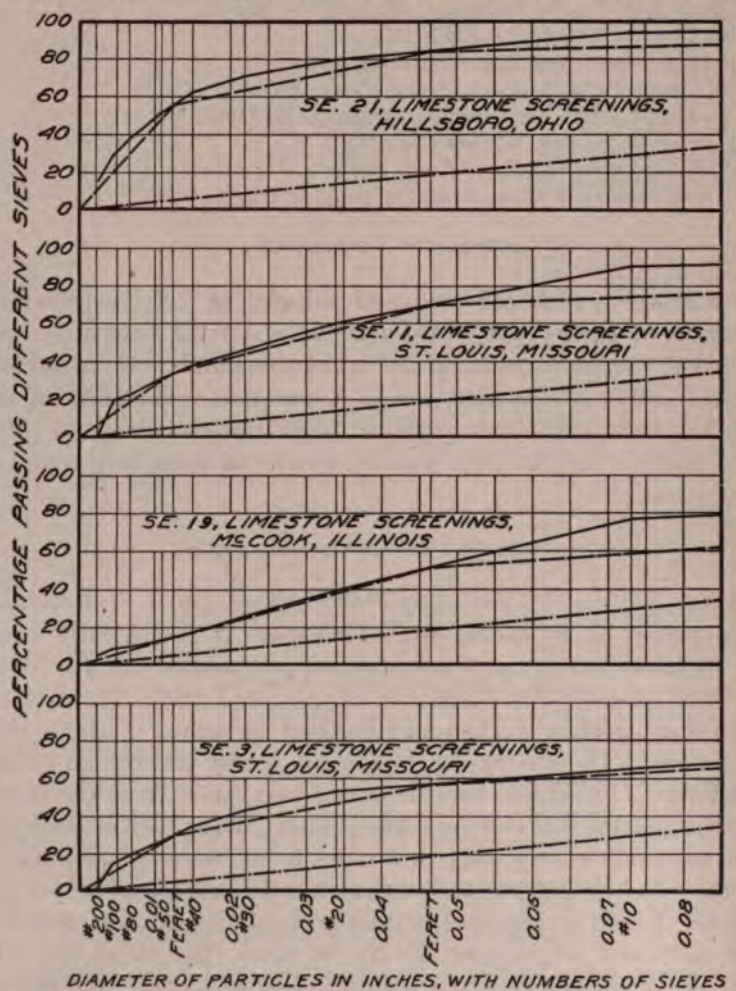


FIG. 17.—Granularmetric analysis curves for stone screenings 21, 11, 19, and 3. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

ings are shown in Table XIV. The appearance is shown in Pl. XIII, *A*.

Register No. Se. 3.—The sample designated Se. 3 was obtained from another quarry at St. Louis. This sample came from the middle bed of the St. Louis limestone, and was blasted out with dynamite and

A *B* *C*

A. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 2).
B. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 3).
C. LIMESTONE SCREENINGS, GLENCOE, MO. (SAMPLE 4).

black powder. The equipment of the quarry embraces compressed-air and steam drills, hoisting machinery, and two large crushers.

Of the crusher-run material as received at the laboratories 23 per cent passed the ¼-inch screen, the large percentage that remained on the ¼-inch screen being about three-eighths inch in size. About 55 per cent passed the No. 20 sieve, and about 15 per cent passed the No. 100 sieve (fig. 17). The percentage of voids is 37; the weight per cubic foot is 103.5 pounds; the amount of silt is 2.3 per cent, and the yield in 1:3 mortar is 1.9. The results of the strength tests of mortars made from these screenings are shown in Table XIV (p. 109). The appearance is shown in Pl. XIII, *B*.

Register No. Se. 4.—A sample from a quarry at Glencoe, St. Louis County, Mo., was designated Se. 4. The outcrop of this rock, an Ordovician limestone, was in the form of a bluff 1,500 feet long and 50 feet high. The stone was excavated by means of black powder and dynamite, and compressed air was largely used in the work.

Of the crusher-run material as received at the laboratories 13½ per cent passed the ¼-inch screen. As may be seen by the granularmetric analysis curve (fig. 22, p. 105) and the illustration (Pl. XIII, *C*), the screenings that passed the ¼-inch screen were almost uniformly graded. The granularmetric analysis curve, shown by solid line in the figure, almost coincides with the uniform-grade line, shown by dots and dashes. Only 20 per cent of this material passed the ¼-inch screen, and only about 5 per cent passed the No. 100 sieve. The percentage of voids is 36; the weight per cubic foot is 105.5 pounds; the amount of silt is 0.6 per cent, and the yield in 1:3 mortar is 1.08. The results of the strength tests of mortars made from these screenings are shown in Table XIV (pp. 109–124).

Register No. Se. 5.—Sample designated Se. 5 was collected at a limestone quarry in Springfield, Mo. The dimensions of the quarry, which is geologically in the Boone formation, were about 200 by 100 by 20 feet. The rock was quarried by means of a steam drill and the use of black powder and dynamite. Both the dimension and crusher-run stones find a ready market in Springfield, Mo., for building purposes.

Of the entire run as received at the laboratories 33 per cent passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 22, p. 105), these screenings are very uniformly graded. About 20 per cent passed the No. 10 sieve and about 12 per cent passed the No. 20 sieve. The percentage of voids is 41.1; the weight per cubic foot is 95.7 pounds; the amount of silt is 1 per cent, and the yield in 1:3 mortar is 1.02. The results of the strength tests of mortars made from these screenings are shown in Table XIV. An illustration of this sample is shown in Pl. XIV, *A*.

Register No. Se. 6.—The sample designated Se. 6 was obtained from a lead mine just west of Joplin, Mo., where a number of lead-bearing veins occur in limestone of the Boone formation. The vein stuff or gangue exists principally in the form of chert, and in the process of separating the galena this chert is crushed into small

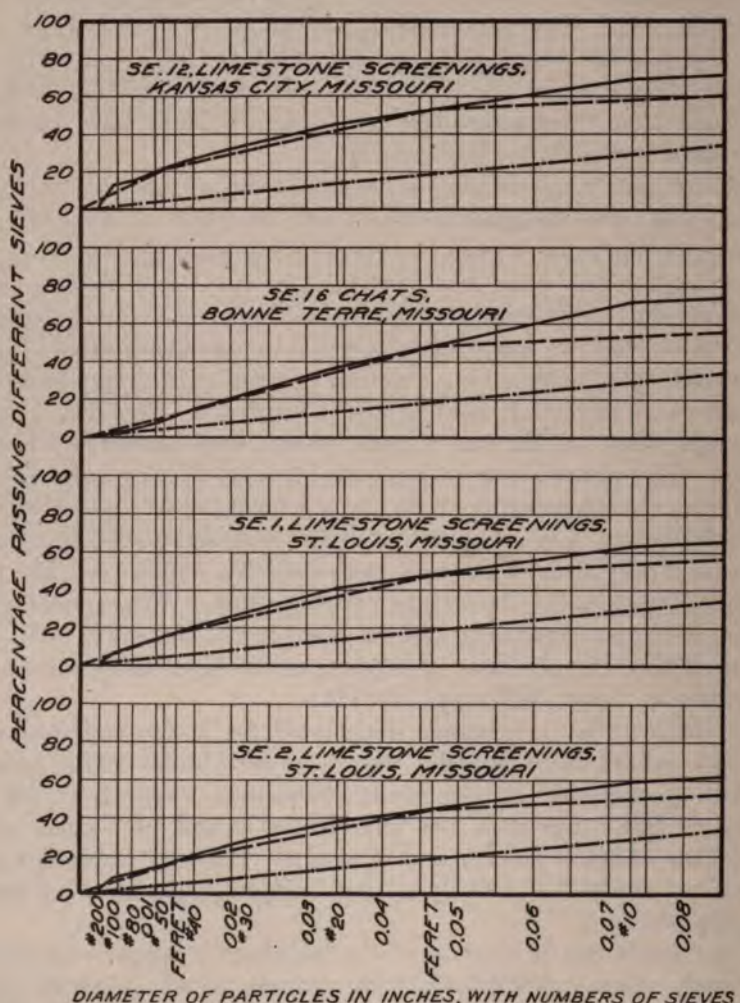
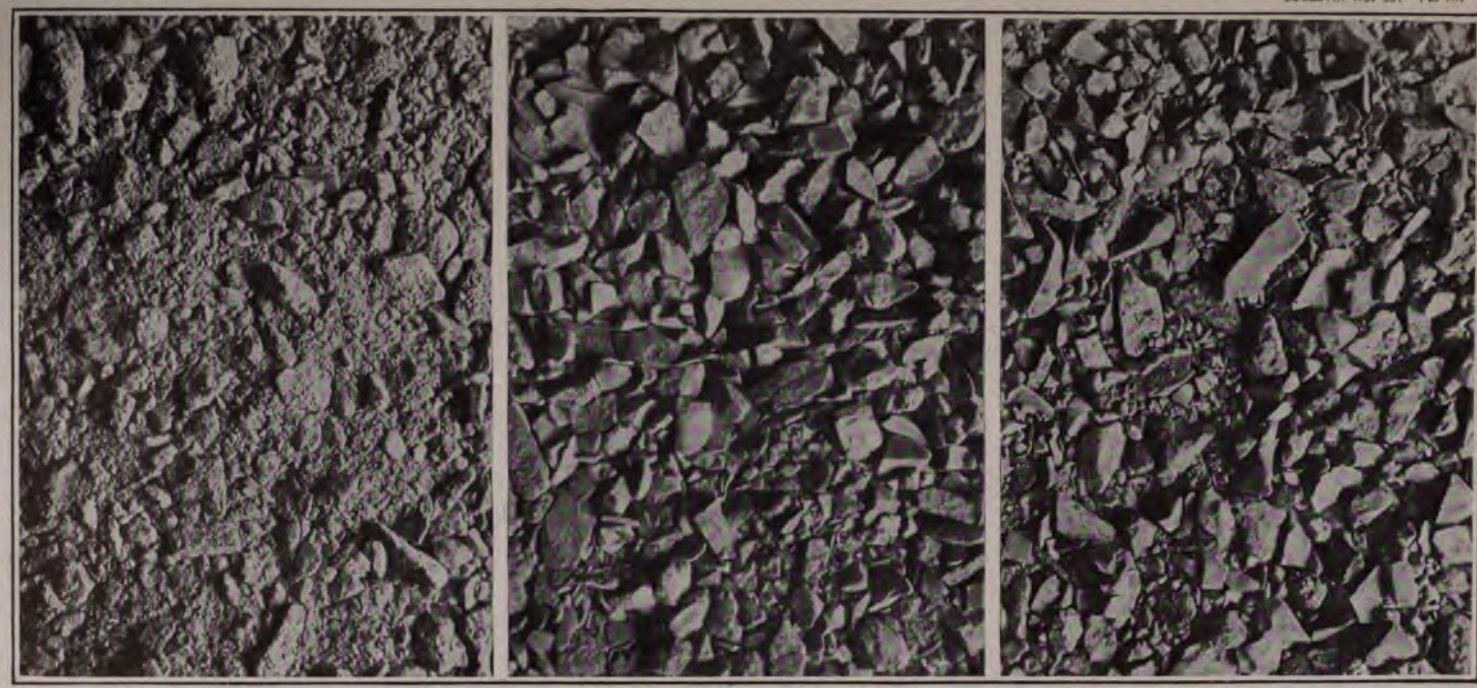


FIG. 18.—Granularmetric analysis curves for stone screenings 12, 16, 1, and 2. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

particles and wasted as lead tailings or chats. The larger of these particles are used as ballast and as an ingredient of concrete; the screenings are used to some extent for mortar.

All the material received at the laboratories passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 22, p.



A *B* *C*

A. LIMESTONE SCREENINGS, SPRINGFIELD, MO. (SAMPLE 5).
B. CHATS, JOPLIN, MO. (SAMPLE 6).
C. CHATS, JOPLIN, MO. (SAMPLE 7).

105), the material is very uniformly graded down to the No. 10 sieve, but below this there is too large an amount of fine material, more than 10 per cent passing the No. 100 sieve. In a general way this may be seen in the illustration (Pl. XIV, *B*). The percentage of voids is 33.1; the weight per cubic foot is 109.5 pounds; the amount of silt is 7 per cent, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from these chats are given in Table XIV.

Register No. Se. 7.—A second sample from Joplin, Mo., designated Se. 7, was obtained from about the same locality and in the same way as Se. 6, described above, but from a different mine.

Like Se. 6, the entire run of crusher passed the ¼-inch screen; but this was found to be somewhat finer than Se. 6, 53 per cent passing the No. 10 sieve, and about 6 per cent passed the No. 80 sieve. The percentages of voids is 36.1; the weight per cubic foot is 102.7 pounds; the amount of silt is 4.9 per cent; and the yield in 1:3 mortar is 1.07. The results of the tests on mortar made from this material are given in Table XIV (pp. 109–124). The granularmetric analysis curve is shown in fig. 20 (p. 100) and an illustration from photograph in Pl. XIV, *C*.

Register No. Se. 8.—The material designated Se. 8 is a sample of the chats taken from a mine just west of Joplin, Mo.

Of the crusher-run material received at the laboratories, a very small portion was retained on the ¼-inch screen, 82 per cent passing through. From the granularmetric analysis curve shown (fig. 20, p. 100), it is seen that the material is not far from uniform grading. It contains a very small amount of fine material, 7 per cent passing the No. 80 sieve. The percentage of voids is 34.6; the weight per cubic foot is 105.5 pounds; the amount of silt is 2.9 per cent, and the yield in 1:3 mortar is 1.03. The results of the strength test of mortars made from this material are given in Table XIV (pp. 109–124).

An illustration of these chats is shown in Pl. XV, *A*, from which the comparatively uniform grading of this material is at once evident, and there does not appear to be a preponderance of either large or very fine particles.

Register No. Se. 9.—A sample of chats from a lead mine near Joplin, Mo., procured in about the same way as Se. 6 (p. 96), was designated Se. 9.

The greater portion of the entire run of crusher received at the laboratories passed the ¼-inch screen. These screenings show a comparatively uniform grading, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 33; the weight per cubic foot is 108 pounds; the amount of silt is 3 per cent; and the yield in 1:3 mortar is 1.12. The results of the strength tests of

mortars made from these chats are given in Table XIV (p. 109). This sample is illustrated in Pl. XV, *B*.

Register No. Se. 10.—A fifth sample collected in the Joplin district was designated Se. 10. It is similar to the chats previously described, and is a by-product of a lead mine.

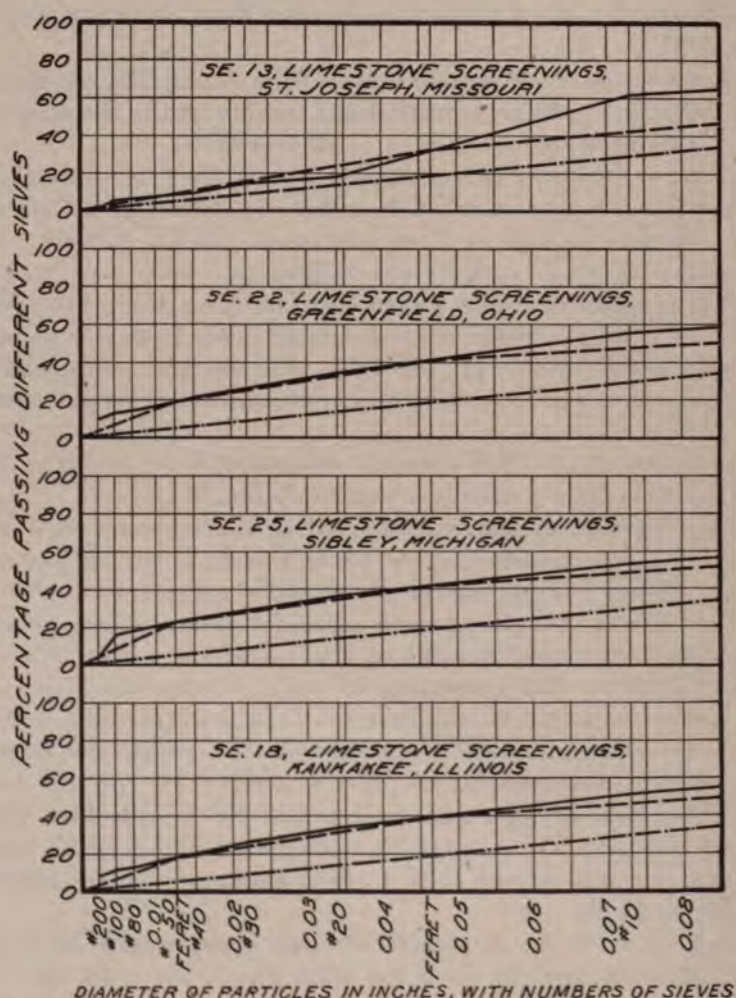


FIG. 19.—Granuarmetric analysis curves for stone screenings 13, 22, 25, and 18. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

Almost all the crusher-run material received at the laboratories passed the ¼-inch screen; about 35 per cent of these screenings passed the No. 20 sieve, and 10 per cent passed the No. 80 sieve. The granularmetric analysis curve is shown in fig. 20 (p. 100) and an illustration from photograph in Pl. XV, *C*. The percentage of voids is

A *B* *C*

A. CHATS, JOPLIN, MO. (SAMPLE 8).
B. CHATS, JOPLIN, MO. (SAMPLE 9).
C. CHATS, JOPLIN, MO. (SAMPLE 10).

31.8; the weight per cubic foot is 109.8 pounds; the amount of silt is 4.7 per cent, and the yield in 1:3 mortar is 1.11. The results of the strength tests of mortars made from this material are given in Table XIV.

Register No. Se. 11.—The sample designated Se. 11 was obtained from a quarry recently opened in the upper central portion of the St. Louis limestone, near St. Louis, Mo. The material was being taken by wagons to St. Louis.

Of the crusher-run material received at the laboratories 50 per cent passed the ¼-inch screen. The grading of the screenings is not at all uniform, as shown by the granularmetric analysis curve (fig. 17, p. 94). Ninety per cent of the material passed the No. 10 sieve; 60 per cent passed the No. 20 sieve, and over 20 per cent passed the No. 100 sieve. The percentage of voids is 42; the weight per cubic foot is 95.5 pounds; the amount of silt is 10.1 per cent, and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). This sample is illustrated in Pl. XVI, *A*. The dirty appearance of the stone indicates the large percentage of silt.

Register No. Se. 12.—Sample designated Se. 12 was quarried in the vicinity of Kansas City, Mo., from limestone of the Pennsylvanian series. The material was excavated by means of steam drills and the use of powder and dynamite, and shipped to Kansas City. This stone is rather soft, and the large amount of dust and small grains resulting from the crushing is shown by the granularmetric analysis curve (fig. 18, p. 96) and by the illustration (Pl. XVI, *B*).

Register No. Se. 13.—The sample designated Se. 13 is a Pennsylvanian (Bethany) limestone, obtained from a quarry in Buchanan County, Mo. The crusher-run material was obtained by the usual methods of steam drilling, blasting, and crushing, and the output was shipped to the vicinity of St. Joseph, Mo.

Of the entire run of crusher received at the laboratories 29 per cent passed the ¼-inch screen. The granularmetric analysis (fig. 19) shows that the material approaches uniform grading. There are many medium and coarse grains and very little fine material in the screenings. The amount of voids is 38.2 per cent; the weight per cubic foot is 102.2 pounds; the amount of silt is 2.2 per cent, and the yield in 1:3 mortar is 1.04. The results of the strength tests of mortars made from these screenings are given in Table XIV. This sample is illustrated in Pl. XVI, *C*. The irregular grading and the comparatively large amount of coarse and medium grains are evident.

Register No. Se. 14.—The sample designated Se. 14 is limestone of Pennsylvanian age obtained from a quarry in Jackson County, Mo. The usual methods were used in quarrying the stone, which was shipped to Kansas City.

Of the entire run of crusher received at these laboratories, 29 per cent passed the ¼-inch screen, and these screenings were found to be very uniformly graded, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 35.8; the weight per cubic foot is 104.3 pounds; the amount of silt is 4.0 per cent,

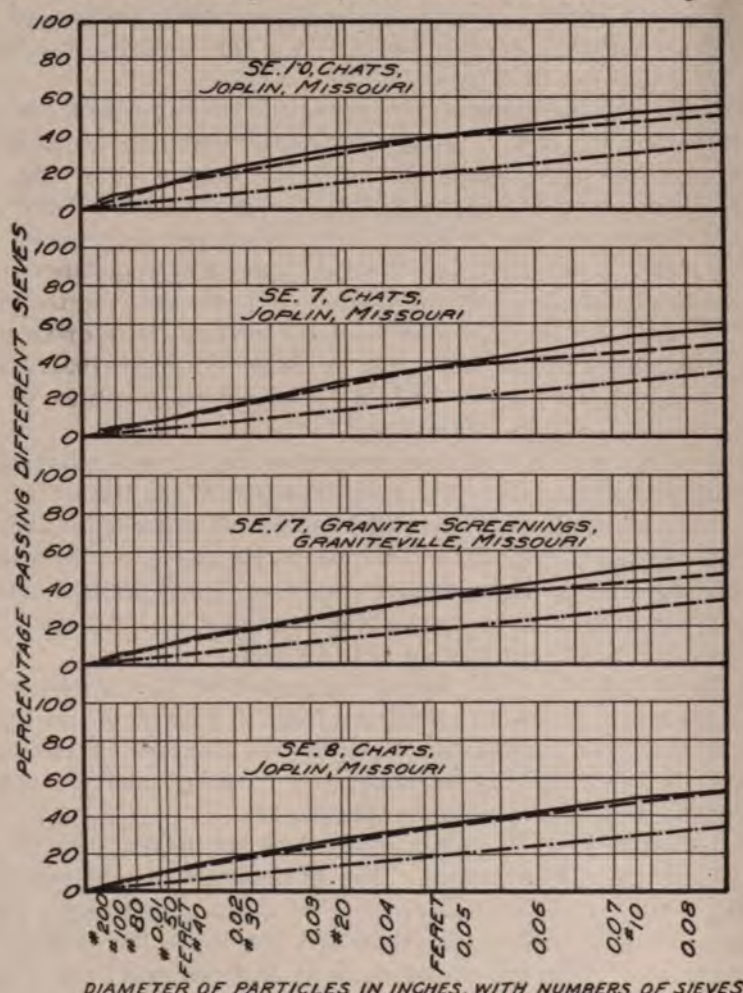
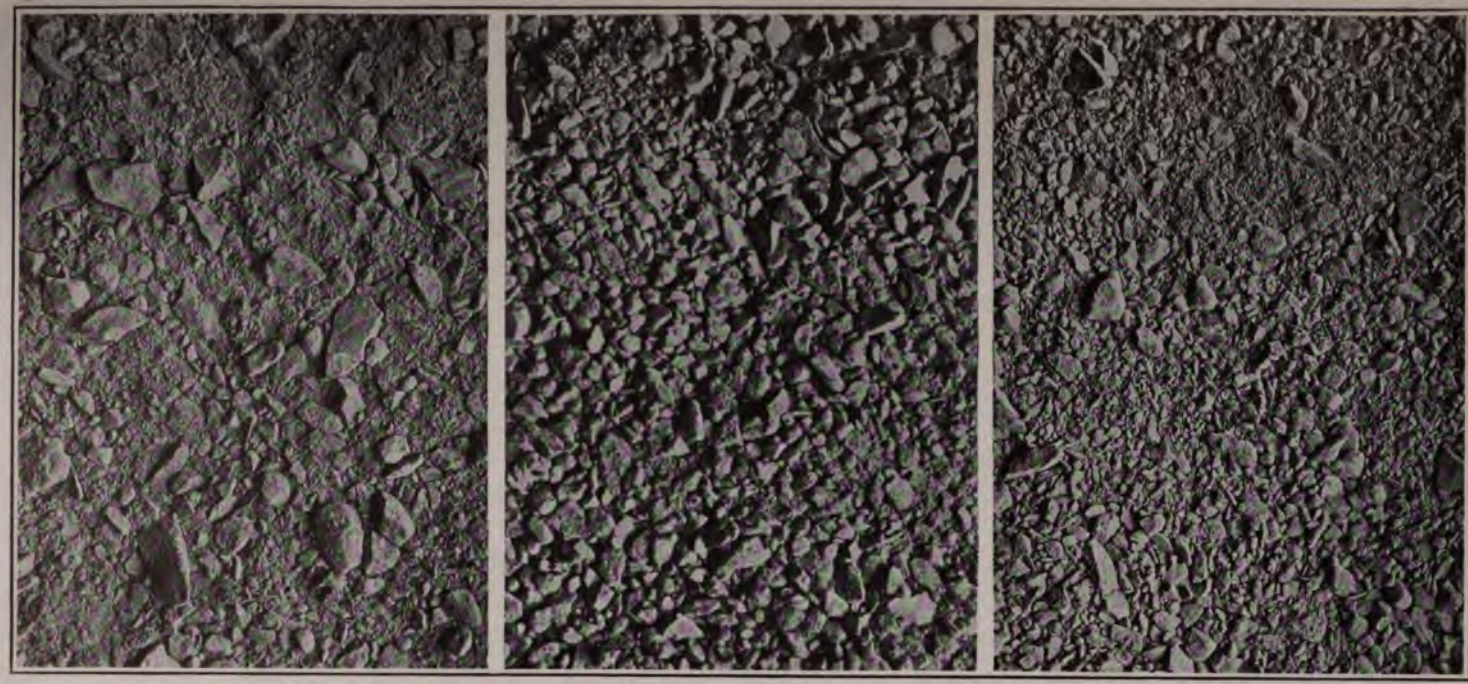


FIG. 20.—Granularmetric analysis curves for stone screenings 10, 7, 17, and 8. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

and the yield in 1:3 mortar is 1.07. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124). The illustration of this material (Pl. XVII, *A*) indicates the uniform grading of particles, from the smallest up to the ¼-inch size, all being plainly visible.



A *B* *C*

A. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 11).
B. LIMESTONE SCREENINGS, KANSAS CITY, MO. (SAMPLE 12).
C. LIMESTONE SCREENINGS, ST. JOSEPH, MO. (SAMPLE 13).

Of the entire run of crusher received at these laboratories, 29 per cent passed the ¼-inch screen, and these screenings were found to be very uniformly graded, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 35.8; the weight per cubic foot is 104.3 pounds; the amount of silt is 4.0 per cent,

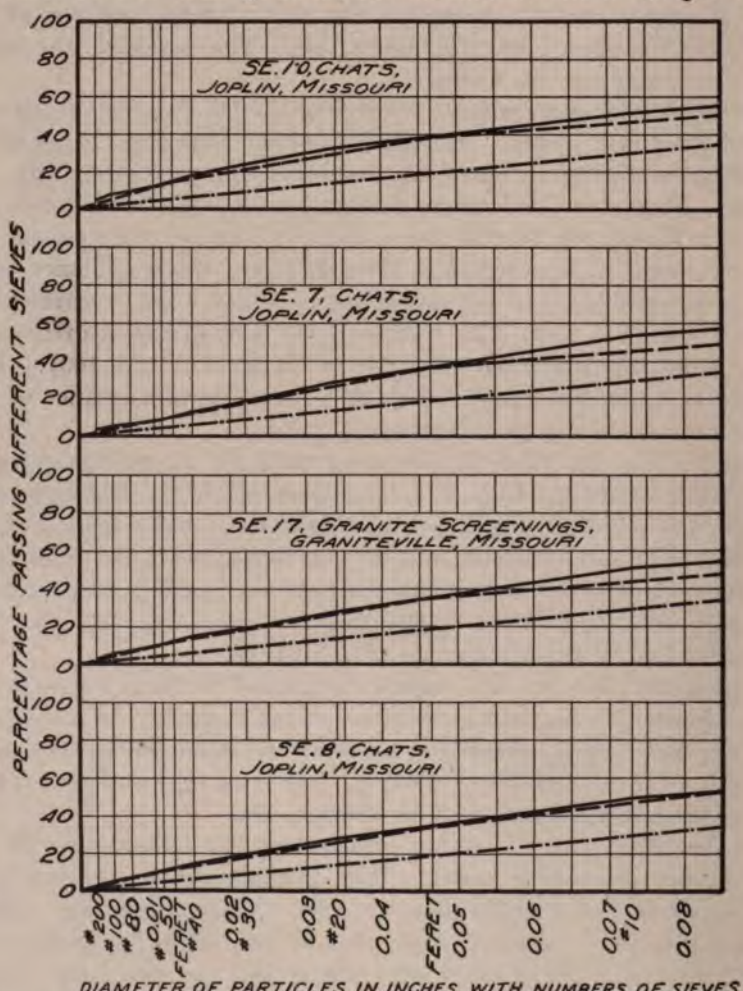
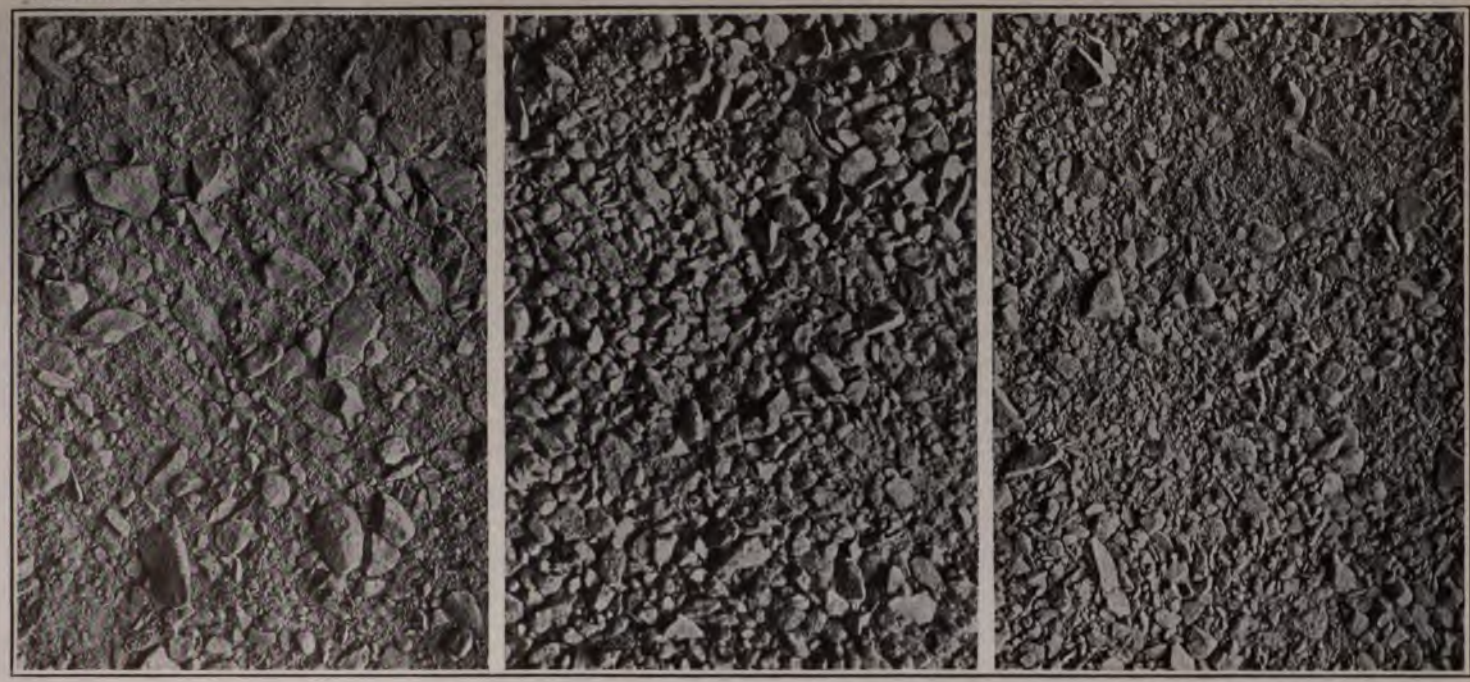


FIG. 20.—Granularmetric analysis curves for stone screenings 10, 7, 17, and 8. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

and the yield in 1:3 mortar is 1.07. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124). The illustration of this material (Pl. XVII, *A*) indicates the uniform grading of particles, from the smallest up to the ¼-inch size, all being plainly visible.



A *B* *C*

A. LIMESTONE SCREENINGS, ST. LOUIS, MO. (SAMPLE 11).
B. LIMESTONE SCREENINGS, KANSAS CITY, MO. (SAMPLE 12).
C. LIMESTONE SCREENINGS, ST. JOSEPH, MO. (SAMPLE 13).

Register No. Se. 15.—Sample designated Se. 15 is obtained from a mine at Hoffman, Mo. Galena is associated with this limestone, and the chats are the calcareous by-product noticeably free from chert. The material is thoroughly washed before marketing in order to eliminate the fine dust.

The entire run of crusher received at these laboratories passed the ¼-inch screen. The granularmetric analysis curve (fig. 22, p. 105) and the illustration (Pl. XVII, *B*) show the absence of any fine grains, there being practically nothing finer than the No. 30, but the curve approaches the uniform-grade line. The percentage of voids is 37; the weight per cubic foot is 109.5 pounds; the amount of silt is 0.5 per cent, and the yield in 1:3 mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 16.—Sample Se. 16 was a by-product from a lead mine in the vicinity of Bonneterre, Mo. It is similar to Se. 15, except that the grading is somewhat different.

The granularmetric analysis curves are shown in fig. 18 (p. 96) and the illustration from photograph in Pl. XVII, *C*. The entire run of crusher, as received at the laboratories, passed the ¼-inch screen, and about 70 per cent of these screenings passed the No. 10 sieve. The percentage of voids is 32.1; the weight per cubic foot is 120 pounds; the amount of silt is 3.7 per cent, and the yield in 1:3 mortar is 1.05. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 17.—The sample designated Se. 17 was obtained from a quarry at Graniteville, Mo. It is a red granite of very close texture, and geologically is of pre-Cambrian age. The excavated rock is cut partly into dimension stones for building purposes, or Belgian blocks for paving. The resulting spalls are passed through a crusher and then through the 1-inch, ½-inch, and ¼-inch screens, each size being conducted to its own bin by a spout. The screenings are shipped to St. Louis or other cities in the Southwest.

Of the entire run of crusher, as received at the laboratories, 44 per cent passed the ¼-inch screen, showing that the three spouts mentioned above do not furnish equal quantities of the three sizes. According to the granularmetric analysis curve (fig. 20, p. 100) the screenings were uniformly graded; this may also be seen in the illustration from photograph (Pl. XVIII, *A*). The percentage of voids is 34.7; the weight per cubic foot is 108.8 pounds; the amount of silt is 1.4 per cent; and the yield in 1:3 mortar is 1.13. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 18.—Sample Se. 18 was obtained from a quarry in a bed of fossiliferous "Niagara" limestone near Kankakee, Ill.

The limestone in this region varies perceptibly in texture, that obtained in this quarry being probably the hardest and closest to be found. The stratum was 5 feet 6 inches thick, over a length of 1,800 feet, and contains a ¼-inch layer of soft argillaceous stone. The rock was excavated by means of steam drills and the use of black powder

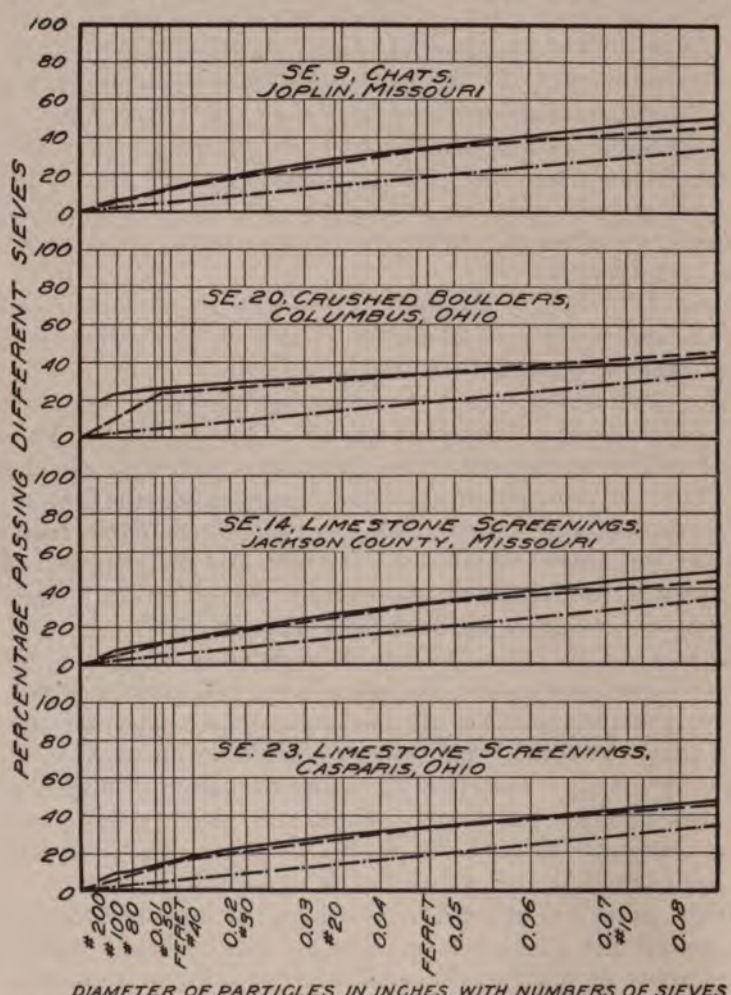
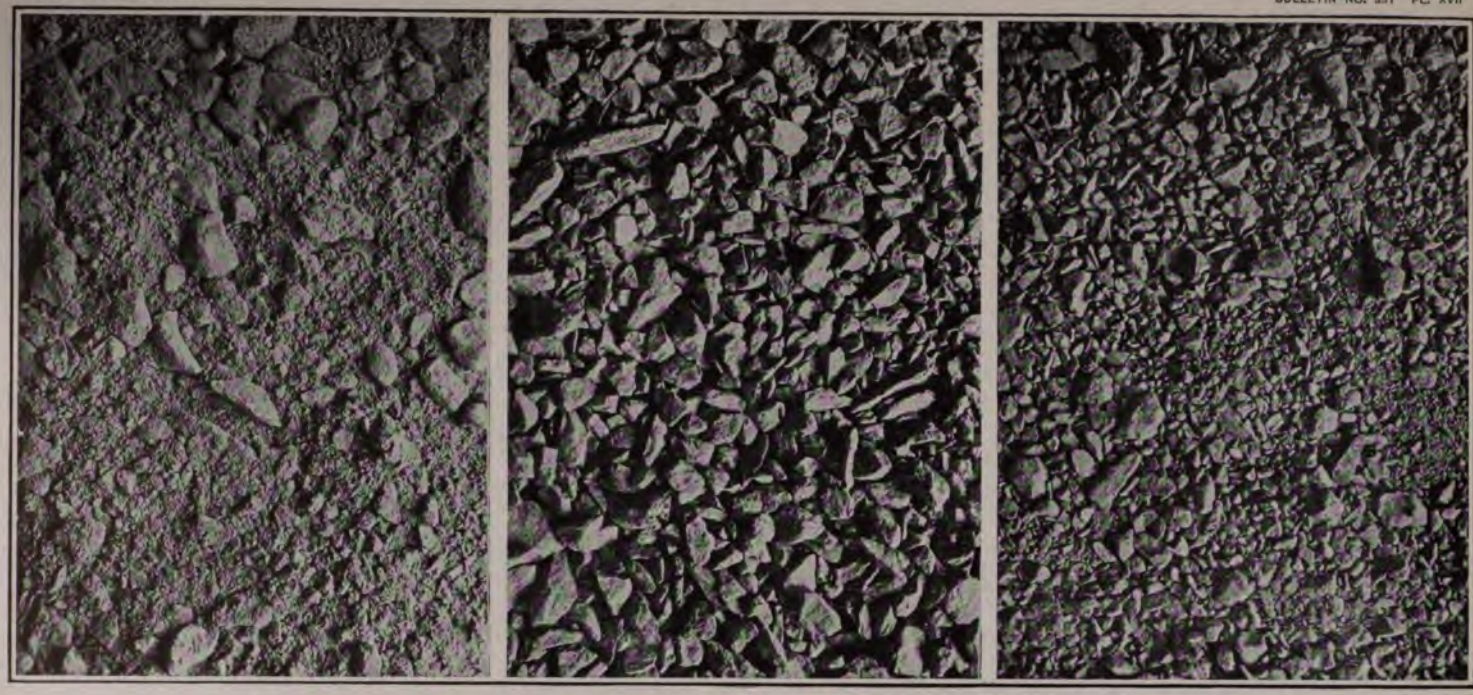


FIG. 21.—Granularmetric analysis curves for stone screenings 9, 20, 14, and 23. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

in blasting. The entire output is passed through a crusher and is not sorted by sieves; it was being shipped to Chicago and Milwaukee.

Of the entire run of crusher, as received at the laboratories, 49 per cent passed the ¼-inch screen. As shown in fig. 19 (p. 98) and the illustration from photograph (Pl. XVIII, *B*), this material is very uniformly graded; but it contains a large amount of fine material,



A *B* *C*

A. LIMESTONE SCREENINGS, JACKSON COUNTY, MO. (SAMPLE 14).
B. CHATS, HOFFMAN, MO. (SAMPLE 15).
C. CHATS, BONNETERRE, MO. (SAMPLE 16).

over 10 per cent passing the No. 100 sieve and 9 per cent passing the No. 200 sieve. The percentage of voids is 39.0; the weight per cubic foot is 103.8 pounds; the amount of silt is 7.48 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars are given in Table XIV (pp. 109–124).

Register No. Se. 19.—The sample designated Se. 19 was obtained from a quarry situated in dolomitic beds of the "Niagara" formation at McCook, Ill. The material was excavated by means of compressed-air drills and the use of black powder in blasting. Part of the material is formed into dimension and paving stones; the remainder is passed through a crusher.

Of the entire run of crusher, as received at the laboratories, 39 per cent passed the ¼-inch screen, and of these screenings 75 per cent passed the No. 10 sieve and 10 per cent passed the No. 100 sieve. The granularmetric analysis curve is shown in fig. 17 (p. 94). The percentage of voids is 39.3; the weight per cubic foot is 102.5 pounds; the amount of silt is 5.0 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars made from this material are given in Table XIV. This sample is illustrated in Pl. XVIII, *C*.

Register No. Se. 20.—Sample Se. 20 was obtained by dredging a strip of the Scioto River bed about 500 feet long at Columbus. The material, as raised by an endless-chain device and dumped into scows, is a mixture of bowlders, gravel, and sand. The bowlders are passed through a crusher and then again mixed with the gravel and sand.

Of the entire run of crusher, as received at the laboratories, 17 per cent passed the ¼-inch screen. As indicated by the granularmetric analysis curve (fig. 21) only about 40 per cent passed the No. 10 sieve, 22 per cent the No. 100, and 20 per cent the No. 200. The percentage of voids is 35.2; the weight per cubic foot is 108.5 pounds; the amount of silt is 3.1 per cent, and the yield in 1:3 mortar is 1.21. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). The illustration of this material (Pl. XIX, *A*) does not truly represent the grading, as all the fine material has settled to the bottom and does not appear on the surface. The large amount of coarse material in this mixture is readily apparent.

Register No. Sec. 21.—Sample Se. 21 is from a quarry near Hillsboro, Ohio, and the stone is of Silurian age. The rock was handled by means of compressed-air drills, powder, and dynamite. Two sizes are prepared for commercial purposes. The coarser size passes the 1½-inch screen and is retained on the ¼-inch screen. The smaller size passes the ¼-inch screen.

Of the screenings, as received at the laboratories, the entire amount passed the ¼-inch screen. According to the granularmetric analysis curve (fig. 17, p. 94) 72 per cent passed the No. 30 sieve and 30 per

cent the No. 100 sieve. The percentage of voids is 41; the weight per cubic foot is 97.4 pounds; the amount of silt is 3.1 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

From the illustration of these screenings (Pl. XIX, *B*) the very small amount of coarse material and the exceedingly large amount of fine material is readily apparent.

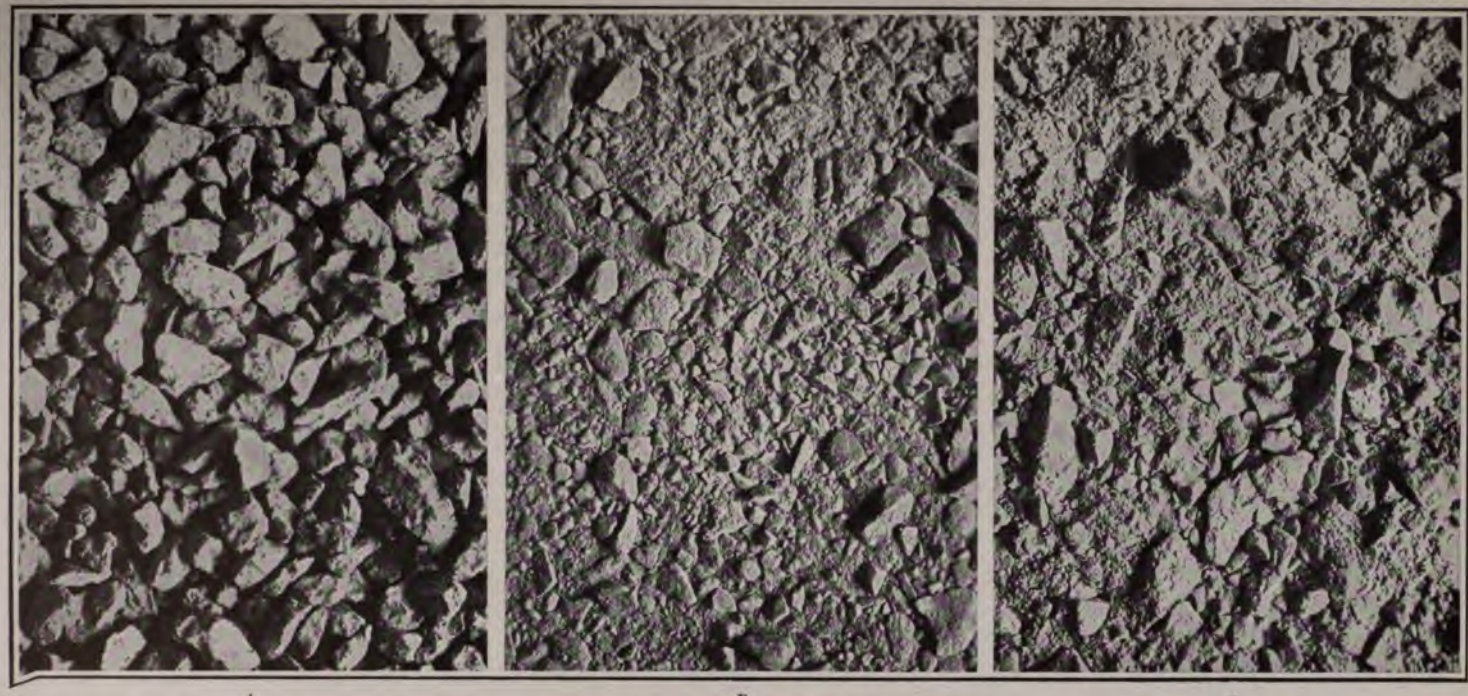
Register No. Se. 22.—Sample Se. 22 belongs to the Monroe formation, found in the vicinity of Greenfield, Ohio, which was being quarried and shipped to Cincinnati. The quarry has a length of about 500 feet, and the rock was blasted by means of black powder and an explosive known to the trade as "rack-a-rock." The ¼-inch screenings removed from the crusher-run material are used for mortar purposes, and the material above one-fourth inch and below 2 inches is used for concrete.

Of the ¼-inch screenings, received at the laboratories, about 15 per cent passed the No. 100 sieve and 10 per cent passed the No. 200 sieve. According to the granularmetric analysis curve (fig. 19, p. 98) the screenings, aside from the large amount of fine material, are uniformly graded. The percentage of voids is 37.5; the weight per cubic foot is 106.3 pounds; the amount of silt is 1.1 per cent, and the yield in 1:3 mortar is 1.14. The results of the strength tests of mortars made from these screenings are given in Table XIV (p. 109). The comparatively large amount of fine material and the presence of grains of all sizes, from the smallest up to the ¼-inch size, is readily apparent from the illustration (Pl. XIX, *C*).

Register No. Se. 23.—Sample Se. 23 is a Devonian limestone obtained from a quarry at Casparis, Ohio. It is very much foliated, and is practically the blanket side of the quarry, which is 8,000 feet long by 65 feet high. The material is obtained by means of air drills and dynamite, and is marketed in Illinois, Indiana, and Ohio. The crushed stone is passed over ¼-inch screens and the material that passes these screens is sold as screenings.

All the particles of this sample as received at the laboratories passed the ¼-inch screen. They are very uniformly graded, as shown by the granularmetric analysis curve (fig. 21, p. 102). The percentage of voids is 38.2; the weight per cubic foot is 99.7 pounds; the amount of silt is 3.5 per cent, and the yield in 1:3 mortar is 1.06. The results of the strength tests of mortars made from these screenings are given in Table XIV (p. 109). The appearance is shown in Pl. XX, *A*.

Register No. Se. 24.—Material designated Se. 24 is a dolomitic limestone in the Monroe formation (Silurian) from a quarry at Silica, about 4 miles from Sylvania, Lucas County, Ohio. The stone is quarried from an open face by means of dynamite, and the material is



A *B* *C*

A. GRANITE SCREENINGS, GRANITEVILLE, MO. (SAMPLE 17).
B. LIMESTONE SCREENINGS, KANKAKEE, ILL. (SAMPLE 18).
C. LIMESTONE SCREENINGS, McCOOK, ILL. (SAMPLE 19).

handled automatically, crushed, and passed through 1-, 2-, and 3-inch screens. On this account no crusher-run material was available. After screening, the material is washed. This company has a most elaborate plant for storing and handling the various products, the conveying and handling machinery being similar to that used in the handling of coal.

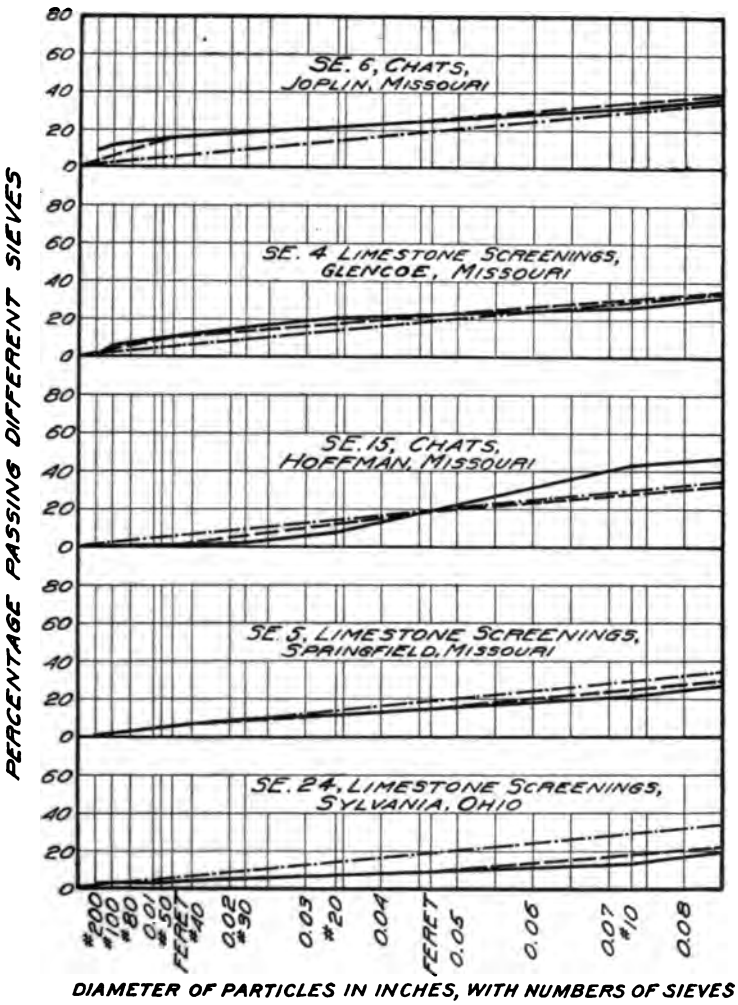


FIG. 22.—Granularmetric analysis curves for stone screenings 6, 4, 15, 5, and 24. Results for sieves Nos. 10, 20, 30, 40, 50, 80, and 100 shown by solid lines; for Feret's two-sieve method by broken lines; uniform-grade lines shown by dots and dashes.

According to the granularmetric analysis curve (fig. 22) this material is rather uniformly graded. This is also illustrated in Pl. XX, *B*. The percentage of voids is 41.8; the weight per cubic foot is 101 pounds; the amount of silt is 1.1 per cent, and the yield in 1:3

mortar is 1.12. The results of the strength tests of mortars made from this material are given in Table XIV (pp. 109–124).

Register No. Se. 25.—A sample from Sibley, Mich., was designated Se. 25.

According to the granularmetric analysis curve for this material (fig. 19, p. 98) it is very uniformly graded, and about 16 per cent passes the No. 100 sieve. The percentage of voids is 33.8; the weight per cubic foot is 110.3 pounds; the amount of silt is 16.3 per cent. The results of the strength tests of mortars made from this material are given in Table XIV (p. 109). The sample is illustrated in Pl. XX, *C*.

PHYSICAL TESTS OF STONE SCREENINGS.

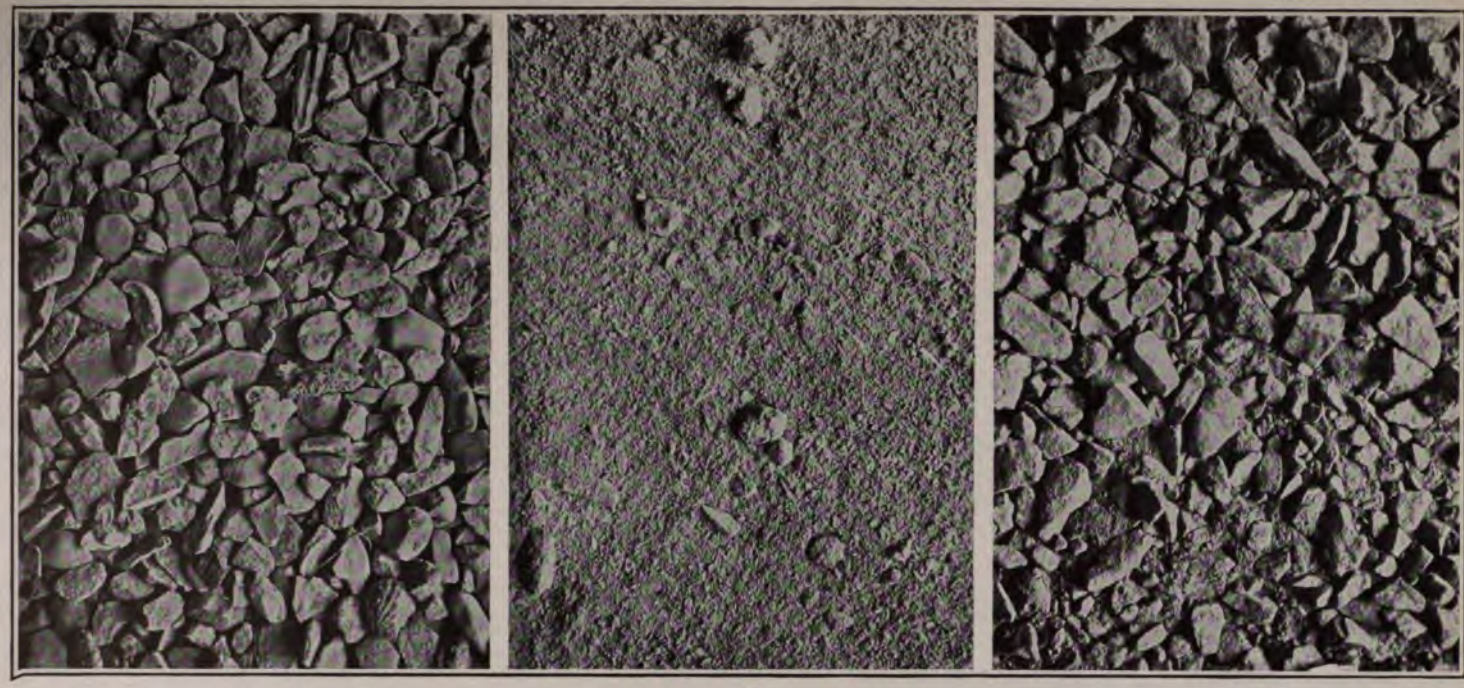
Method.—When a sample of broken stone is received at the laboratories it is spread on a concrete floor, and turned at frequent intervals, so that it will thoroughly dry. It is then passed over a ¼-inch screen, and the material that passes the screen is used in the mortar tests. The material retained on the ¼-inch screen is discarded. The portion to be used is tested for granularmetric composition, percentage of voids, specific gravity, weight per cubic foot, and percentage of moisture. The results of these determinations are given in Table VIII (p. 59). The percentage and chemical analysis of silt are given in Table X (p. 77).

Granularmetric analysis.—The set of sieves for the granularmetric analysis comprises those with 10, 20, 30, 40, 50, 80, 100, and 200 openings per linear inch.

Granularmetric curves.—The granularmetric analysis curves are shown in figs. 17–22, the ordinate at any sieve being the total percentage that passes that sieve, and not, as in Table VIII (p. 59), the percentage retained by the sieve. Starting with the curve of the screenings having the largest amount of fine material (Se. 21), at the top of fig. 17 (p. 94), these curves are arranged in consecutive order, ending with the curve of the screenings having the largest amount of coarse material (Se. 24), at the bottom of fig. 22 (p. 105).

The granularmetric analysis curves, as determined by the standard sieves previously referred to, are given in solid lines. In order to illustrate the difference between this method of analysis and the two-sieve method proposed by M. Feret, the curve representing the analysis by the latter method is plotted on the same chart in broken lines. Below the two curves just described is given the uniform-grade line in dots and dashes. From the finest to the coarsest screenings the curves have been arranged in the order of the size of the segment included between the granularmetric analysis curve and the uniform-grade line.

Comparison between measured and computed voids.—In order to determine the accuracy of the method of void determination used at



A *B* *C*

A. SCREENINGS FROM CRUSHED BOWLDERS, COLUMBUS, OHIO (SAMPLE 20).
B. LIMESTONE SCREENINGS, HILLSBORO, OHIO (SAMPLE 21).
C. LIMESTONE SCREENINGS, GREENFIELD, OHIO (SAMPLE 22).

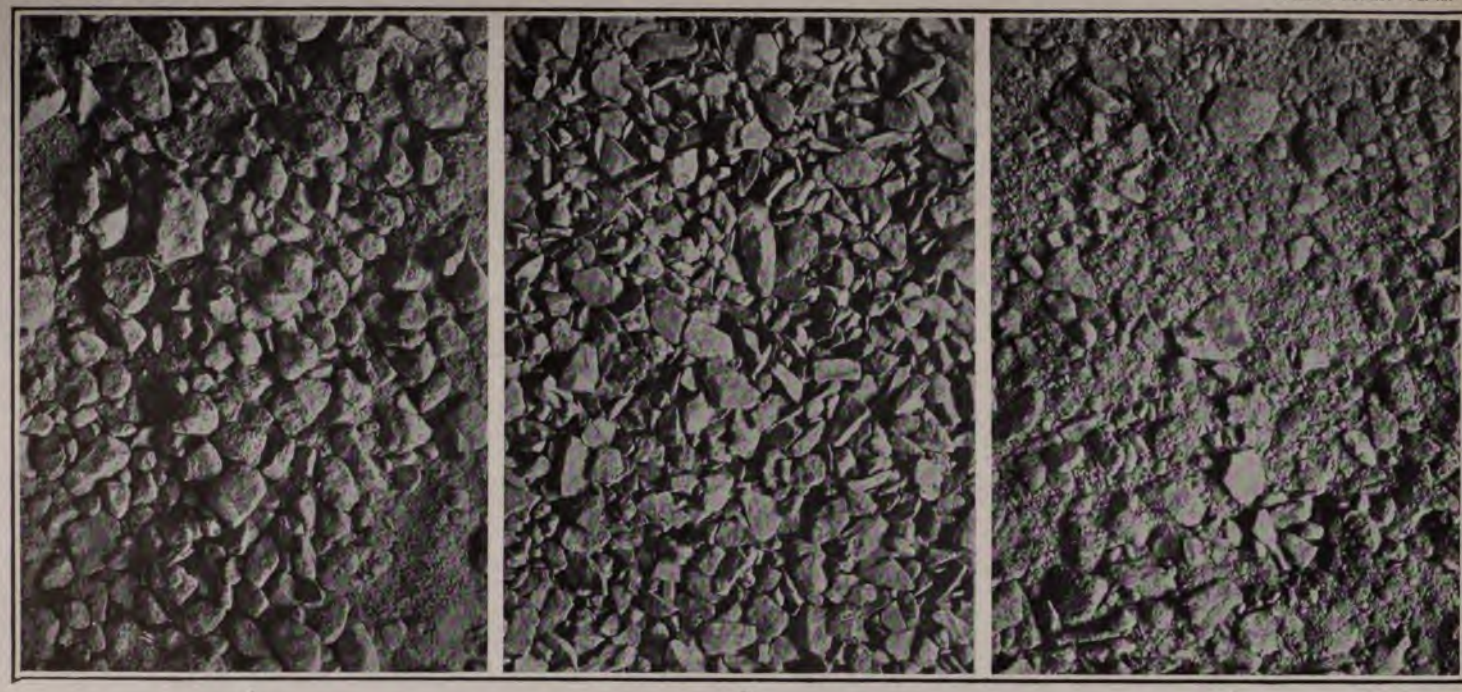
strength of mortars made from those samples having lesser voids is greater than the strength of mortars made from those in which the voids are greater.

Compressive strength.—The results of the compressive tests on 1:3, on 1:4, and on 1:3 one-size stone-screenings mortar are given in Table XIV*b* (p. 115). The values in this table are in pounds per square inch and are obtained by dividing the total breaking load by the area of cross section of a 2-inch cube.

As in the case of tensile strength, there is a slight indication that the strength of stone-screenings mortar is greater for a sample for which the granularmetric analysis curve is close to the uniform grade line than for one for which the granularmetric analysis curve is farther removed from that line. In addition, the strength appears to increase with the decrease of voids.

Transverse strength.—The results of the transverse tests on 1:3, on 1:4, and on 1:3 one-size stone-screenings mortar are given in Table XIV*c* (p. 121). The values given in this table are moduli of rupture in pounds per square inch. At the time of writing not all of the 360-day transverse test pieces have been tested, and it is, therefore, impossible at this time to complete the tables giving the results of the tests. This is due to the fact that the transverse molds did not arrive until some time after the other test pieces had been made. A study of the table shows that the transverse strength gradually increases up to 90 days in almost every case. Beyond this the strength does not vary much to 360 days, in some cases increasing and in some cases decreasing slightly.

Summary of stone-screenings mortar tests.—In general, more confidence can be attached to the tests of the older test pieces than to those of the earlier test pieces. In the case of homogeneous materials the results of tests of different mortars at the same age should be somewhat uniform or should follow some general law, such as that observed in the case of sands where the position of the granularmetric analysis curve was seen to indicate the comparative strength of the mortars. In the investigations on stone screenings, however, since the stones were obtained in many different places, the results of the tests on test pieces of the same age are not consistent. It can not be said that any definite law can be given by means of which the strength of stone mortar can be approximately foretold by the mechanical conditions, since the strength of the stone from which the screenings are derived has much to do with the strength of the mortar. Almost the same difficulty was found with stone-screenings mortars as with gravel-screenings mortars (p. 88): that is, the tendency of the cement to concentrate at one or more parts of the sections. This was noticed principally where the material was composed of large



A *B* *C*

A. LIMESTONE SCREENINGS, CASPARIS, OHIO (SAMPLE 23).
B. LIMESTONE SCREENINGS, SYLVANIA, OHIO (SAMPLE 24).
C. LIMESTONE SCREENINGS, SIBLEY, MICH. (SAMPLE 25).

grains. The results of the tests of pieces in which this took place were very discordant.

The solid stone, obtained from the same quarry and the same bed from which the crushed stone is collected, is being tested for its physical properties. The results of these tests (which are to appear in another bulletin discussing the constituent materials of concrete) may afford a basis for the comparison of the relative value of mortars made from stone screenings.

Density.—The density of mortar made from each sample of stone screenings was determined in order to ascertain its relation to the other physical properties, and to see if the strength of mortar can be approximately foretold by the density. The density of 1:3 stone-screenings mortar and the relation between the density and other physical properties of stone and mortar are given in Table XII (p. 79). In column 1 are given the register numbers of the stone screenings used in the mortars whose densities are given in column 2. The densities are ranged consecutively, with the largest value at the top. For purposes of comparison the number of the granularmetric analysis curve for each sample of stone screenings is given in column 3. The numbers start with No. 1 for Se. 21 (at the top of fig. 17, p. 94) and end with No. 25 for Se. 24 (at the bottom of fig. 22, p. 105). The percentage of voids, weight per cubic foot, and the tensile, compressive, and transverse strengths of the corresponding mortars at 180 days are given in columns 4–8. It can be seen that in the upper part of the table, where the values of density are greatest, the percentages of voids as a rule are least and the weights per cubic foot and the strengths are greatest, and at the bottom of the table the opposite is true.

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 1	1:3	1.04	79–1	66.2	67.6	9.1	362	663	760	698	678
							342	645	840	728	800
							325	710	830	696	805
	Average						343	673	810	707	761
	1:4		79–6	65.8	64.1	8.4	375	546	618	662	637
							425	557	517	637	620
							390	561	600	645	628
	Average						397	555	588	648	628
	1:3 sifted		79–11	74.0	70.0	8.9	400	458	444	550	467
							380	445	425	512	482
							365	440	480	497	464
	Average						385	448	450	520	471

[a] For details of field origin of samples of stone screenings see pp. 93–106.
[b] In tests marked "sifted" the stone screenings used were sifted through No. 10 and over No. 20 size.

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.10	79-1	66.2	67.9	9.1	285	540	664	790	610
							261	541	600	721	686
							298	600	620	792	702
	Average						281	560	628	768	666
	1:4		79-6	65.8	64.1	8.4	370	411	550	676	586
							384	420	590	661	579
							380	474	600	715	606
	Average						378	435	580	684	590
	1:3 (sifted)		79-11	74.0	70.0	8.9	345	473	592	669	563
							365	475	530	600	547
							341	509	600	687	529
	Average						350	486	574	652	546
Se. 3	1:3	1.09	79-2	63.5	59.0	9.1	366	691	748	828	724
							375	606	757	793	733
							375	730	755	805	789
	Average						372	676	753	809	749
	1:4		79-7	66.2	66.5	8.4	455	555	700	756	642
							435	558	672	717	664
							465	595	690	730	672
	Average						452	569	687	734	659
	1:3 (sifted)		79-11	74.0	70.0	8.9	345	392	630	642	497
							360	379	660	612	468
							329	424	600	655	490
	Average						345	398	630	636	485
Se. 4	1:3	1.08	79-2	63.5	59.0	9.1	510	630	919	970	772
							550	680	973	936	830
							560	610	963	910	796
	Average						540	640	952	939	799
	1:4		79-7	66.2	66.5	8.4	414	516	714	845	756
							452	552	790	830	765
							428	529	777	800	769
	Average						431	532	760	825	763
	1:3 (sifted)		79-12	71.6	68.0	8.9	335	477	570	570	456
							303	447	540	547	502
							400	477	570	.....	511
	Average						346	467	560	559	490
Se. 5	1:3	1.02	79-3	66.9	53.2	9.1	360	620	690	762	736
							345	613	625	740	771
							325	580	670	780	728
	Average						343	604	662	761	745
	1:4		79-8	65.8	66.2	8.4	400	495	660	670	602
							365	490	550	671	614
							370	496	555	.....	592
	Average						378	494	588	670	603
	1:3 (sifted)		133-14	78.8	77.0	8.3	369	493	506	445	575
							379	490	473	446	556
	Average						374	492	490	445	566

TABLE XIVa.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 6	1:3	1.11	79-3	66.9	53.2	9.1	377	600	725	745	637
							400	645	790	756	664
							388	660	800	750	700
	Average						388	635	772	750	667
	1:4		79-8	65.8	66.2	8.4	413	580	790	692	715
							439	567	743	700	705
							385	591	725	.....	724
	Average						412	579	753	696	715
	1:3 (sifted)		79-12	71.6	68.0	8.9	352	490	500	630	495
							335	470	590	620	506
							350	495	542	.....	478
	Average						346	485	543	625	493
Se. 7	1:3	1.07	79-3	66.9	53.2	9.1	370	616	660	650	655
							382	585	652	690	586
							336	600	718	690	649
	Average						363	600	677	677	630
	1:4		79-8	65.8	66.2	8.4	392	425	592	595	533
							357	430	520	627	532
							350	460	558	.....	527
	Average						366	438	557	611	531
	1:3 (sifted)		79-12	71.6	68.0	8.9	330	350	400	.....	374
							335	330	370	452	358
							325	325	365	433	380
	Average						330	335	378	442	371
Se. 8	1:3	1.03	79-4	68.0	59.3	9.1	515	684	785	795	756
							517	633	790	780	790
							547	683	728	805	784
	Average						526	667	768	793	777
	1:4		79-9	63.6	51.4	8.4	412	594	660	760	623
							409	599	697	720	618
							400	570	678	750	611
	Average						407	588	678	743	617
	1:3 (sifted)		79-13	70.5	68.0	8.9	365	420	575	472	415
							340	400	555	474	411
							330	395	540	452	452
	Average						345	405	557	466	426
Se. 9	1:3	1.12	79-4	68.0	59.3	9.1	518	630	730	787	722
							526	694	792	835	720
							550	637	799	826	738
	Average						531	654	774	816	727
	1:4		79-9	63.6	51.4	8.4	386	550	648	775	602
							418	511	586	700	620
							403	510	660	771	618
	Average						402	524	631	749	613
	1:3 (sifted)		79-13	70.5	68.0	8.9	270	395	410	489	387
							290	347	365	440	346
							280	390	410	.....	352
	Average						280	377	395	464	362

TABLE XIVa.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 10..	1:3	1.11	79-4	68.0	59.3	9.1	485	629	805	770	720
							470	645	735	776	687
							510	659	780	756	712
	Average						488	644	773	767	706
	1:4		79-9	63.6	51.4	8.4	333	440	605	682	584
							289	490	637	660	592
							293	475	560	655	575
	Average						305	468	601	666	584
	1:3 (sifted)		79-13	70.5	68.0	8.9	280	312	413	472	395
							250	309	362	473	379
							268	339	383	498	402
	Average						266	320	386	481	392
Se. 11..	1:3	1.12	79-5	66.2	56.1	9.1	355	451	492	530	645
							335	433	510	560	667
							340	455	524	540	642
	Average						343	446	509	543	651
	1:4		79-10	59.8	69.4	8.3	215	323	410	442	416
							225	320	420	470	435
							245	301	418	492	420
	Average						228	315	416	468	424
	1:3 (sifted)		79-14	71.6	68.0	8.9	365	468	473	580	563
							380	448	455	565	532
							345	438	500	635	546
	Average						363	451	476	593	547
Se. 12..	1:3	1.13	79-5	66.2	56.1	9.1	400	657	744	745	608
							375	623	742	727	620
							390	617	715	678	613
	Average						388	632	734	717	613
	1:4		79-10	59.8	69.4	8.3	415	565	635	673	678
							420	600	657	672	645
							440	590	623	678	683
	Average						425	585	638	674	699
	1:3 (sifted)		79-14	71.6	68.0	8.9	430	565	703	701	675
							410	550	630	711	684
							425	522	660	697	705
	Average						422	546	664	703	688
Se. 13..	1:3	1.04	79-5	66.2	56.1	9.1	462	642	719	810	678
							463	682	768	771	705
							450	625	768	840	691
	Average						458	650	752	807	691
	1:4		79-10	59.8	69.4	8.3	415	550	675	673	615
							400	575	610	702	633
							445	560	600	692	642
	Average						420	562	628	689	630
	1:3 (sifted)		79-14	71.6	68.0	8.9	390	505	645	703	633
							377	470	600	683	623
							400	560	615	724	608
	Average						389	512	620	703	621

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Tensile strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 14..	1:3	1.07	79-16	71.6	59.7	8.9	488	622	728	666	579
							495	678	775	645	689
							520	620	730	680	600
	Average						501	640	744	664	623
	1:4		79-18	69.0	68.9	8.3	453	565	695	555	632
							410	550	640	560	695
							449	574	710	591	696
	Average						437	563	682	569	674
	1:3 (sifted)		79-20	69.8	67.6	8.9	420	500	520	480	621
							405	540	580	440	579
							390	512	555	485	560
	Average						405	517	552	468	587
Se. 15..	1:3	1.12	79-21	70.5	54.3	8.9	630	574	620	645	685
							600	589	600	675	692
							595	623	574	.....	740
	Average						608	595	598	660	706
	1:4		79-22	71.6	68.2	8.3	300	365	460	565	410
							295	361	450	590	436
							290	332	470	.....	492
	Average						295	358	460	578	446
	1:3 (sifted)		79-23	71.2	68.0	8.9	304	427	440	386	490
							300	450	420	395	445
							333	468	458	330	460
	Average						312	448	439	370	465
Se. 16..	1:3	1.05	79-21	70.5	54.3	8.9	430	717	787	765	856
							480	745	775	764	870
							473	700	800	771	842
	Average						461	721	787	767	856
	1:4		79-22	71.6	68.2	8.3	380	602	695	704	755
							371	565	730	680	741
							396	570	725	700	739
	Average						382	579	717	695	745
	1:3 (sifted)		79-24	70.7	52.0	8.9	300	447	430	442	357
							320	403	400	425	364
							300	418	450	460	406
	Average						307	423	427	442	376
Se. 17..	1:3	1.13	79-16	71.6	59.7	8.9	420	550	615	591	522
							424	530	608	570	561
							382	530	610	535	522
	Average						409	537	611	565	535
	1:4		79-18	69.0	68.9	8.3	371	450	425	448	437
							360	435	450	400	455
							345	447	385	.....	437
	Average						359	444	420	424	443
	1:3 (sifted)		135-4	78.8	82.4	8.9	232	330	337	425	487
							260	316	398	376	473
							241	341	380	432	534
	Average						244	329	372	411	498

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water. (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 18	1:3	1.06	79-25	71.6	73.4	8.9	370	527	640	650	740
							394	530	664	618	712
							381	545	620	600	708
	Average						382	534	641	623	720
	1:4		79-25	71.6	73.4	8.3	323	418	550	530	650
							320	425	555	560	628
							340	458	552	545	.....
	Average						328	434	552	545	639
	1:3 (sifted)		79-25	71.6	73.4	8.9	455	634	725	752	640
							448	610	709	750	631
							440	643	675	730	.....
	Average						448	629	703	744	635
Se. 19	1:3	1.06	79-19	74.8	66.2	8.9	455	636	750	750	838
							510	656	695	820	742
							500	681	747	800	843
	Average						488	658	731	790	808
	1:4		79-19	74.8	66.2	8.3	400	580	690	715	815
							405	600	682	693	890
							375	580	710	660	823
	Average						393	587	694	689	843
	1:3 (sifted)		79-20	69.8	67.6	8.9	456	670	785	804	771
							445	673	725	805	810
							465	640	735	795	792
	Average						455	661	748	801	791
Se. 20	1:3	1.21	79-35	70.0	70.4	8.9	355	485	574	536	610
							345	492	558	495	562
							347	476	547	485	556
	Average						349	484	560	505	576
	1:4		79-35	70.0	70.4	8.3	300	400	527	476	510
							322	440	483	464	474
							326	410	521	.....	.....
	Average						316	417	510	470	492
Se. 21	1:3	1.14	79-31	70.7	70.0	8.9	420	535	630	705	661
							400	524	600	660	637
							437	554	640	.....	668
	Average						419	538	623	683	655
	1:4		79-31	70.7	70.0	8.3	350	460	548	570	627
							345	460	570	540	620
							355	455	560	560	592
	Average						350	458	559	557	613
	1:3 (sifted)		79-31	70.7	70.0	8.9	410	515	621	635	748
							425	525	657	650	764
							430	535	665	681	750
	Average						422	525	648	655	754
Se. 22	1:3	1.14	79-34	69.8	69.8	8.9	528	603	800	850	902
							503	645	853	924	936
							497	610	845	998	942
	Average						509	619	833	924	927
	1:4		79-34	69.8	69.8	8.3	428	560	685	770	770
							442	530	720	760	782
							470	527	768	746	796
	Average						447	539	724	758	783

TABLE XIV*a*.—*Tensile strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Tensile strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 23	1:3	1.06	79–37	68.0	68.4	8.9	345	485	542	541	560
							339	497	550	545	587
							360	481	556	551	571
	Average						348	488	549	545	573
	1:4		79–37	68.0	68.4	8.3	320	438	500	504	450
							308	431	495	520	481
							312	400	525	500	.....
	Average						313	423	507	508	465
Se. 24	1:3	1.12	79–48	69.8	66.2	8.9	385	435	525	650	701
							373	467	.....	.....	738
							383	423	500	780	753
	Average						380	442	512	715	731
	1:4		79.48	69.8	66.2	8.3	331	372	415	487	578
							334	350	445	495	439
							333	360	.....	485	456
	Average						333	361	430	489	491
Se. 25	1:3		133–40	71.6	71.6	8.9	438	570	583	690	691
							412	529	650	640	718
							406	560	591	639	731
	Average						419	553	608	656	713
	1:4		133–40	71.6	71.6	8.3	388	500	600	655	651
							390	475	540	720	690
							360	502	615	722	674
	Average						379	492	585	699	672
	1:3 (sifted)		133.40	71.6	71.6	8.9	277	426	507	630	545
							287	383	550	625	545
							245	385	500	650	602
	Average						270	398	519	635	564

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 1	1:3	1.04	79–1	69.0	68.7	8.9	2,375	3,580	4,740	5,458	6,000
							2,650	3,950	4,795	5,073	5,662
							2,637	3,620	5,038	.....	5,327
	Average						2,554	3,717	4,858	5,263	5,663
	1:4		79–8	71.6	68.2	8.3	1,862	2,337	3,435	3,563	4,875
							1,987	2,262	3,475	3,758	4,250
							2,000	2,100	3,400	3,788	4,750
	Average						1,949	2,233	3,437	3,703	4,625
	1:3 (sifted)		79–15	69.8	70.0	8.9	1,175	1,617	1,715	2,150	2,750
							1,152	1,540	1,500	2,355	2,400
							1,287	1,467	1,670	2,213	2,575
	Average						1,205	1,541	1,628	2,239	2,575

[a] For details of field origin of samples of stone screenings see pp. 93–106.
[b] In tests marked "sifted" the stone screenings used were through No. 10 and over No. 20 size.

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.10	79-1	69.0	68.7	8.9	2,500	3,410	4,135	5,190	5,467
							2,352	3,375	4,500	5,508	5,380
							2,545	3,162	4,595	5,055	5,525
	Average						2,466	3,316	4,410	5,251	5,457
	1:4		133-7	71.6	68.2	8.3	1,512	2,575	3,312	4,070	4,640
							1,572	2,625	3,570	4,370	5,125
							1,676	2,750	3,717	4,320	4,800
	Average						1,587	2,650	3,533	4,253	4,855
	1:3 (sifted)		79-16	70.7	70.0	8.9	1,500	2,025	2,460	2,950	2,775
							1,570	2,037	2,098	.....	2,500
							1,455	1,982	2,650	2,888	2,625
	Average						1,508	2,015	2,403	2,919	2,633
Se. 3	1:3	1.09	79-2	74.8	66.2	8.9	2,750	4,712	5,435	6,688	5,900
							3,025	4,512	5,525	6,193	5,877
							3,037	4,825	5,775	6,618	6,270
	Average						2,937	4,683	5,578	6,500	6,016
	1:4		79-9	71.2	68.0	8.3	2,185	3,550	4,338	5,193	5,278
							2,212	3,687	4,338	5,020	5,082
							2,335	3,630	4,475	4,875	4,958
	Average						2,244	3,622	4,384	5,029	5,106
	1:3 (sifted)		79-16	70.7	70.0	8.9	1,362	1,870	1,765	2,250	2,900
							1,210	1,945	1,985	2,413	2,550
							1,365	2,080	1,750	2,338	2,825
	Average						1,312	1,965	1,833	2,334	2,758
Se. 4	1:3	1.08	79-3	74.8	66.2	8.9	3,225	5,632	.....	8,328	7,855
							3,625	5,362	6,450	8,800	7,375
							3,375	5,925	6,235	8,805	8,185
	Average						3,408	5,639	6,342	8,644	7,805
	1:4		79-9	71.2	68.0	8.3	1,612	3,450	3,463	4,175	4,538
							1,660	3,257	2,812	3,908	5,125
							1,760	3,612	3,078	4,193	5,040
	Average						1,677	3,439	3,118	4,092	4,901
Se. 5	1:3	1.02	79-3	69.8	67.6	8.9	2,450	3,927	4,213	4,915	6,590
							2,250	3,570	4,450	4,993	6,155
							2,525	4,362	4,438	.....	5,840
	Average						2,408	3,953	4,367	4,954	6,195
	1:4		79-10	70.7	52.0	8.3	1,362	1,705	2,048	2,475	4,400
							1,187	1,837	2,000	.....	4,250
							1,262	1,985	1,975	2,500	4,225
	Average						1,370	1,842	2,008	2,488	4,292
Se. 6	1:3	1.11	79-3	69.8	67.6	8.9	3,725	5,250	7,200	8,160	8,875
							3,525	5,025	7,133	8,445	8,837
							3,462	5,517	6,925	7,538	8,859
	Average						3,571	5,264	7,086	8,048	8,859
	1:4		79-10	70.7	52.0	8.3	1,700	3,137	4,900	5,313	5,375
							1,602	3,000	4,500	5,143	5,400
							1,555	2,775	4,500	5,570	5,500
	Average						1,639	2,971	4,633	5,342	5,524

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 7...	1:3	1.07	79-4	69.8	67.6	8.9	1,875	2,787	4,358	5,328	5,488
							1,735	3,062	4,520	5,508	5,580
							1,830	2,545	4,420	5,000	5,137
	Average						1,813	2,798	4,433	5,279	5,402
	1:4		79-11	73.4	57.2	8.3	925	1,662	2,250	2,265	3,175
							937	1,652	2,320	2,318	3,300
							850	1,630	2,338	2,475	3,100
	Average						904	1,648	2,303	2,353	3,192
	1:3 (sifted)		79-16	70.7	70.0	8.9	882	1,162	.....	1,413	1,600
							950	1,042	1,145	.....	1,375
							950	1,135	1,250	1,525	1,650
	Average						927	1,113	1,197	1,469	1,542
Se. 8...	1:3	1.03	79-4	71.6	55.0	8.9	2,775	4,275	5,625	5,945	5,575
							2,797	3,875	5,500	6,500	5,763
							2,950	4,475	5,417	6,475	5,375
	Average						2,841	4,208	5,514	6,307	5,571
	1:4		79-11	73.4	57.2	8.3	1,392	2,800	3,250	4,685	6,050
							1,305	2,855	3,500	4,700	5,725
							1,450	2,597	3,325	4,450	5,900
	Average						1,382	2,751	3,358	4,612	5,892
Se. 9...	1:3	1.12	79-4	71.6	55.0	8.9	2,375	4,075	5,325	6,113	5,560
							2,380	4,137	5,250	5,850	5,525
							2,400	4,350	5,212	.....	5,500
	Average						2,385	4,187	5,262	5,982	5,528
	1:4		79-11	73.4	57.2	8.3	1,312	2,700	3,500	4,198	4,600
							1,435	2,520	3,465	4,300	4,500
							1,450	2,517	3,738	3,768	4,675
	Average						1,399	2,579	3,568	4,089	4,592
	1:3 (sifted)		79-17	70.2	69.8	8.9	750	1,075	1,225	1,310	1,350
							862	1,037	1,350	1,250	1,225
							837	1,130	1,338	1,375	1,550
	Average						816	1,081	1,304	1,312	1,375
Se. 10..	1:3	1.11	79-4	71.6	55.0	8.9	2,750	3,737	4,582	.....	6,852
							2,520	3,450	4,670	7,513	6,887
							2,260	3,450	4,900	7,275	6,677
	Average						2,510	3,546	4,717	7,394	6,805
	1:4		79-12	68.0	60.8	8.3	795	2,007	2,330	2,783	3,100
							750	2,090	2,475	3,220	3,500
							746	1,960	2,250	3,025	3,175
	Average						764	2,019	2,352	3,009	3,258
	1:3 (sifted)		79-17	70.2	69.8	8.9	937	1,000	1,850	1,675	1,475
							905	1,112	1,925	1,500	1,400
							840	1,000	1,888	1,580	1,250
	Average						894	1,037	1,888	1,585	1,375
Se. 11..	1:3	1.12	79-5	70.0	64.4	8.9	1,000	2,000	3,155	3,613	4,850
							1,120	2,155	2,925	3,963	4,825
							1,127	2,000	2,925	3,695	5,050
	Average						1,082	2,052	3,002	3,757	4,908
	1:4		79-12	68.0	60.8	8.3	945	1,540	2,338	2,595	3,725
							985	1,662	2,225	2,875	4,050
							905	1,440	2,075	2,750	3,675
	Average						945	1,547	2,213	2,740	3,813
	1:3 (sifted)		79-17	70.2	69.8	8.9	1,625	.....	3,325	2,588	4,300
							1,712	2,270	3,513	2,713	4,250
							1,500	2,075	3,513	2,560	4,325
	Average						1,612	2,171	3,450	2,620	4,292

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 12..	1:3	1.13	79-6	69.6	60.3	8.9	2,512	4,525	5,175	6,168	6,400
							3,000	4,470	5,362	6,208	7,225
							2,812	4,500	5,332	6,203	6,550
	Average						2,775	4,498	5,290	6,193	6,725
	1:4		79-13	68.0	73.4	8.3	1,675	3,000	3,950	4,175	6,050
							1,580	2,825	3,650	4,100	5,700
							1,590	2,962	3,643	.....	5,650
	Average						1,615	2,929	3,748	4,138	5,800
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,305	1,585	1,930	1,633	1,950
							1,350	1,460	2,000	1,775	1,875
							1,375	1,482	2,085	1,775	2,025
	Average						1,377	1,509	2,008	1,728	1,950
Se. 13..	1:3	1.04	79-6	69.6	60.3	8.9	2,700	4,550	5,025	5,533	6,150
							2,500	4,250	5,250	5,000	5,700
							2,450	4,426	5,015	5,650	5,675
	Average						2,550	4,409	5,097	5,394	5,842
	1:4		79-13	68.0	73.4	8.3	1,237	2,275	3,475	3,350	3,725
							1,205	2,200	3,138	3,050	4,050
							1,260	2,187	3,000	.....	3,925
	Average						1,234	2,221	3,204	6,200	3,900
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,537	2,055	.....	2,975	3,475
							1,462	2,067	2,558	3,105	3,800
							1,505	2,277	2,788	2,950	3,650
	Average						1,501	2,133	2,673	3,010	3,642
Se. 14..	1:3	1.07	79-6	69.6	60.3	8.9	2,900	4,750	5,730	6,125	7,075
							3,000	4,550	5,610	5,950	7,175
							2,725	4,550	5,825	6,050	6,600
	Average						2,875	4,617	5,722	6,042	6,950
	1:4		79-14	70.7	69.0	8.3	2,042	2,880	4,045	4,688	4,250
							2,080	2,257	.....	4,380	4,600
							2,030	2,905	4,138	4,660	4,475
	Average						2,051	2,681	4,092	4,576	4,442
	1:3 (sifted)		79-18	68.0	66.2	8.9	1,875	2,277	.....	3,250	3,625
							1,777	2,250	2,588	3,075	3,475
							1,805	2,200	2,550	3,313	3,600
	Average						1,819	2,242	2,569	3,213	3,567
Se. 15..	1:3	1.12	79-7	70.5	54.3	8.9	1,712	2,800	5,500	.....	5,480
							1,762	3,087	5,435	4,675	5,675
							1,766	3,225	5,225	4,688	5,800
	Average						1,747	3,037	5,387	4,681	5,652
	1:4		79-14	70.7	69.0	8.3	960	1,025	1,438	1,803	1,075
							875	947	1,400	1,873	1,200
							912	890	1,000	1,725	1,375
	Average						916	954	1,279	1,800	1,217
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,200	2,200	2,625	2,733	2,925
							1,050	2,037	2,520	.....	2,800
							1,177	2,025	.....	2,788	2,650
	Average						1,142	2,087	2,572	2,760	2,792

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Compressive strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 16	1:3	1.05	79-7	70.5	54.3	8.9	1,767	3,500	5,363	4,930	6,875
							1,588	3,462	5,483	5,235	6,537
							2,026	3,750	5,000	4,750	7,010
	Average						1,805	3,571	5,282	4,972	6,807
	1:4		79-15	69.8	70.0	8.3	1,290	2,052	2,963	3,650	4,725
							1,437	2,290	3,148	3,750	5,000
							1,362	2,262	.....	3,525	4,675
	Average						1,363	2,201	3,056	3,642	4,800
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,300	2,165	2,400	1,388	2,800
							1,287	2,237	2,280	1,305	2,975
							1,350	2,275	.....	1,390	2,900
	Average						1,312	2,226	2,340	1,392	2,892
Se. 17	1:3	1.13	79-7	70.5	54.3	8.9	2,187	4,125	4,478	5,310	6,925
							2,075	3,745	4,425	5,515	7,100
							2,400	4,200	4,633	5,113	6,300
	Average						2,221	4,023	4,512	5,313	6,775
	1:4		79-14	70.7	69.0	8.3	987	2,200	3,320	3,853	3,275
							1,112	2,000	2,975	3,618	3,825
							1,055	2,272	3,050	3,778	3,050
	Average						1,051	2,157	3,115	3,750	3,383
	1:3 (sifted)		135-5	78.8	80.6	8.9	2,140	2,750	3,350	3,250	4,025
							2,025	3,000	3,475	2,925	3,875
							1,912	.....	3,375	2,875	4,050
	Average						2,026	2,875	3,400	3,017	3,983
Se. 18	1:3	1.06	79-20	69.8	72.0	8.9	2,425	3,362	5,015	6,443	6,900
							2,275	3,037	4,760	6,208	6,225
							2,262	3,132	4,663	6,013	6,500
	Average						2,321	3,177	4,813	6,221	6,542
	1:4		79-20	69.8	72.0	8.3	1,512	2,500	3,250	4,275	4,475
							1,600	2,567	3,275	4,163	4,800
							1,525	2,287	.....	4,025	4,350
	Average						1,546	2,451	3,262	4,154	4,542
	1:3 (sifted)		79-20	69.8	72.0	8.9	2,350	3,195	4,010	4,775	4,400
							2,250	3,455	4,250	4,900	4,500
							2,150	3,452	4,325	5,225	4,625
	Average						2,250	3,367	4,195	4,967	4,508
Se. 19	1:3	1.06	79-8	71.6	68.2	8.9	2,345	3,785	4,857	5,665	7,075
							2,335	4,000	4,960	5,000	6,050
							2,200	3,500	5,067	5,713	7,150
	Average						2,293	3,762	4,961	5,459	6,758
	1:4		79-15	69.8	70.0	8.3	1,637	2,675	3,560	4,800	6,150
							1,712	2,500	3,575	4,538	5,675
							1,762	2,697	3,695	.....	5,700
	Average						1,704	2,624	3,610	4,669	5,842
	1:3 (sifted)		79-19	69.8	66.2	8.9	1,750	2,517	4,038	3,375	4,250
							1,780	2,845	3,890	3,510	4,475
							1,525	2,605	3,625	3,675	4,225
	Average						1,685	2,656	3,851	3,520	4,317
Se. 20	1:3	1.21	79-35	70.0	70.0	8.9	2,668	4,165	5,408	5,100	6,125
							2,585	4,135	5,155	4,875	6,550
							2,505	3,937	5,488	5,020	6,450
	Average						2,586	4,079	5,350	4,998	6,375
	1:4		79-35	70.0	70.0	8.3	2,000	3,440	4,288	3,612	5,375
							1,913	3,382	4,370	3,631	5,400
							1,925	3,310	.....	3,975	5,375
	Average						1,946	3,377	4,329	3,719	5,383

TABLE XIV*b*.—*Compressive strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Compressive strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 21	1:3	1.14	79-26	70.7	69.0	8.9	1,637	2,525	3,470	3,887	5,305
							1,732	2,400	3,725	4,119	5,270
							1,537	2,250	3,250	3,837	4,850
	Average						1,635	2,392	3,482	3,948	5,142
	1:4		79-26	70.7	69.0	8.3	1,177	1,880	2,675	3,350	4,125
							1,250	1,908	2,578	3,425	4,100
							1,137	1,725	2,733	3,412	4,150
	Average						1,188	1,838	2,662	3,396	4,125
	1:3 (sifted)		79-26	70.7	69.0	8.9	1,387	2,420	3,378	3,650	4,375
							1,375	2,573	3,250	4,137	4,550
							1,440	2,250	3,378	3,575	4,750
	Average						1,401	2,414	3,335	3,787	4,558
Se. 22	1:3	1.14	79-34	69.8	69.8	8.9	2,683	4,682	6,163	7,550	8,675
							2,500	4,650	6,375	7,222	8,600
							2,520	4,682	6,263	7,375	8,225
	Average						2,568	4,671	6,267	7,382	8,500
	1:4		79-34	69.8	69.8	8.3	2,013	3,050	4,763	4,800	6,050
							1,900	3,300	4,600	4,700	5,950
							1,955	3,325	4,575	4,750	5,425
	Average						1,956	3,225	4,646	4,750	5,808
Se. 23	1:3	1.06	79-37	69.8	70.0	8.9	1,543	2,925	3,763	4,225	5,800
							1,595	2,868	3,765	4,512	5,675
							1,550	2,835	3,763	4,350	5,475
	Average						1,563	2,876	3,764	4,362	5,650
	1:4		79-37	69.8	70.0	8.3	1,405	2,298	2,978	2,862	4,400
							1,383	2,392	3,280	3,112	4,150
							1,353	2,375	3,033	3,025	4,100
	Average						1,380	2,355	3,097	2,910	4,217
Se. 24	1:3	1.12	79-48	68.8	62.6	8.9	1,838	2,900	3,080	3,950	4,750
							1,835	2,588	2,943	3,450	4,675
							.....	.....	.....	3,675	5,150
	Average						1,836	2,744	3,011	3,692	4,858
	1:4		79-48	68.8	62.6	8.3	963	1,700	2,268	2,525	2,500
							925	1,925	2,128	2,750	1,625
							978	.....	.....	2,950	1,750
	Average						955	1,812	2,198	2,742	1,958
Se. 25	1:3		133-40	71.6	69.8	8.9	3,270	4,150	5,350	6,600	6,800
							3,390	4,255	4,650	6,375	6,825
							3,348	4,425	4,550	6,275	6,450
	Average						3,346	4,277	4,850	6,417	6,692
	1:4		133-40	71.6	69.8	8.3	3,005	3,092	.....	5,175	4,950
							2,825	3,112	4,125	4,550	4,350
							2,853	3,132	4,575	4,900	4,550
	Average						2,894	3,112	4,350	4,875	4,617
	1:3 (sifted)		133-40	71.6	69.8	8.9	1,763	2,085	2,750	2,800	2,800
							1,885	1,950	2,650	2,625	2,850
							1,783	2,125	2,975	2,725	2,750
	Average						1,810	2,053	2,792	2,717	2,800

TABLE XIVc.—*Transverse strength of the mortars of 25 stone screenings.*

Register No.[a]	Ratio of cement to screenings.[b]	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Transverse strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Se. 2	1:3	1.04	133-6	71.6	64.2	9.1	648	1,134	1,530	1,188	1,404
							702	1,080	1,350	1,224	1,404
							738	1,098	1,440	1,584	1,422
	Average						696	1,104	1,440	1,332	1,410
	1:4		133-7	69.8	64.2	8.4	504	900	1,224	.....	.....
							504	738	1,170	.....	.....
							522	.....	.....	.....	1,152
	Average						510	819	1,197	.....	1,152
Se. 3	1:3	1.10	133-8	69.8	65.4	9.1	756	1,170	1,458	1,368	1,584
							756	1,224	1,350	1,530	1,620
							828	1,116	1,584	1,332	1,548
	Average						780	1,170	1,464	1,410	1,584
	1:4		133-9	69.8	68.0	8.4	648	1,044	1,188	1,296	1,422
							666	990	990	1,260	1,422
							720	1,080	1,080	1,242	1,440
	Average						678	1,038	1,086	1,266	1,428
	1:3 (sifted)		135-13	80.6	80.6	8.7	792	828	918	1,224	972
							576	612	918	1,152	918
							702	720	1,008	1,044	954
	Average						690	720	948	1,140	948
Se. 4	1:3	1.09	133-10	69.8	66.2	9.1	864	1,206	1,530	1,584	1,476
							720	1,098	1,350	1,620	1,422
							900	990	1,260	1,602	1,386
	Average						828	1,098	1,380	1,602	1,428
	1:4		133-11	63.0	70.7	8.4	522	720	1,188	1,206	1,476
							594	828	1,206	1,152	1,512
							.....	900	1,080	1,314	1,566
	Average						558	816	1,158	1,224	1,518
Se. 5	1:3	1.08	133-12	63.0	67.1	9.1	648	1,116	1,242	1,170	1,404
							540	1,116	1,116	1,332	1,350
							702	954	1,152	1,242	1,368
	Average						630	1,062	1,170	1,248	1,374
	1:4		133-13	63.5	74.0	8.4	612	540	864	882	936
							486	756	936	972	882
							504	684	954	846	900
	Average						534	660	918	900	906
	1:3 (sifted)		133-14	66.2	78.8	8.3	468	540	936	1,026	972
							504	630	864	972	.....
							522	.....	.....	900	1,044
	Average						498	585	900	966	1,008
Se. 6	1:3	1.02	133-15	68.0	78.8	9.1	450	1,080	1,152	1,368	1,440
							486	972	1,278	1,368	1,512
							.....	1,116	1,116	1,242	1,440
	Average						468	1,056	1,182	1,326	1,464
	1:4		133-16	67.1	68.0	8.4	738	864	1,224	1,116	1,332
							936	936	1,080	1,296	1,260
							936	1,008	1,350	1,368	1,368
	Average						870	936	1,218	1,260	1,320

[a] For details of field origin of samples of stone screening see pp. 93-106.
[b] In tests marked "sifted" the stone screenings used were sifted through No. 10 and over No. 20 size.

TABLE XIVc.—*Transverse strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.).		Water (per cent).	Transverse strength (pounds per square inch).				
				Water.	Air.		7 days.	28 days.	90 days.	180 days.	360 days.
Sc. 7	1:3	1.11	133-18	68.9	67.1	9.1	612	756	.....	1,224	1,026
							720	738	1,008	1,206	972
							756	1,008	1,026	1,188	972
	Average	.....	.....	.....	.....	.....	696	834	1,017	1,206	990
	1:4	.....	133-19	68.9	77.0	8.4	396	720	936	1,062	756
							450	648	.....	1,188	864
							432	540	828	1,044	.....
	Average	.....	.....	.....	.....	.....	426	636	882	1,098	810
	1:3 (sifted)	.....	133-20	69.8	78.8	8.9	342	594	684	828	738
							342	612	612	792	792
							288	576	702	828	.....
	Average	.....	.....	.....	.....	.....	324	594	666	816	765
Sc. 8	1:3	1.07	133-22	69.8	73.4	9.1	720	1,152	1,314	1,404	1,314
							702	900	1,350	1,296	1,494
							810	1,170	.....	1,422	.....
	Average	.....	.....	.....	.....	.....	744	1,074	1,332	1,374	1,404
	1:4	.....	133-24	69.8	64.0	8.4	504	864	1,170	.....	1,332
							558	990	1,044	1,188	1,368
							.....	900	1,260	1,260	.....
	Average	.....	.....	.....	.....	.....	531	918	1,158	1,224	1,350
	1:3 (sifted)	.....	133-25	68.0	68.7	8.9	432	486	612	846	936
							378	522	558	810	936
							432	702	720	738	.....
	Average	.....	.....	.....	.....	.....	414	570	630	798	936
Sc. 9	1:3	1.03	133-26	68.9	68.0	9.1	774	1,170	1,224	1,530	1,458
							702	1,080	1,278	1,458	1,548
							864	1,152	1,260	1,494	1,476
	Average	.....	.....	.....	.....	.....	780	1,134	1,254	1,494	1,494
	1:4	.....	133-27	68.0	66.2	8.4	612	864	792	1,080	1,260
							630	846	1,026	1,152	1,278
							612	828	972	1,224	1,368
	Average	.....	.....	.....	.....	.....	618	846	930	1,152	1,302
	1:3 (sifted)	.....	133-29	68.9	74.3	8.9	486	756	810	1,008	1,080
							468	720	684	864	.....
							396	702	612	918	.....
	Average	.....	.....	.....	.....	.....	450	726	702	930	1,080
Sc. 10	1:3	1.11	133-30	69.8	69.8	9.1	846	972	1,368	1,098	1,548
							882	1,116	1,296	1,260	1,512
							756	1,044	1,404	1,296	1,656
	Average	.....	.....	.....	.....	.....	828	1,044	1,356	1,218	1,572
	1:4	.....	133-31	68.0	77.0	8.4	540	864	828	990	1,260
							522	936	1,116	1,134	1,224
							630	846	990	1,044	.....
	Average	.....	.....	.....	.....	.....	564	882	978	1,056	1,242
	1:3 (sifted)	.....	133-32	71.6	80.6	8.9	504	630	612	.....	684
							432	774	666	.....	630
							486	648	540	.....	702
	Average	.....	.....	.....	.....	.....	474	684	606	.....	672

TABLE XIVc.—*Transverse strength of the mortars of 25 stone screenings*—Continued.

Register No.	Ratio of cement to screenings.	Yield.	Cement No.	Temperature (°F.). Water.	Temperature (°F.). Air.	Water (per cent).	Transverse strength (pounds per square inch). 7 days.	28 days.	90 days.	180 days.	360 days.
Se. 11..	1:3	1.12	133-33	76.1	74.3	9.1	522	720	828	990	954
							486	900	864	936	900
							468	774	774	828	.....
	Average	.....	.....	.....	.....	.....	492	798	822	918	927
	1:4	.....	133-34	69.8	71.6	8.3	306	540	720	864	918
							324	594	774	828	864
							432	612	864	828	828
	Average	.....	.....	.....	.....	.....	354	582	786	840	870
	1:3 (sifted)	.....	133-35	71.6	68.0	8.9	576	882	1,368	1,404	1,296
							648	936	.....	1,296	1,224
							486	774	1,404	1,368	1,224
	Average	.....	.....	.....	.....	.....	570	864	1,386	1,356	1,248
Se. 12..	1:3	1.13	133-43	70.7	71.6	9.1	864	1,116	1,368	1,296	1,404
							882	900	1,260	1,620	1,404
							846	1,008	1,296	1,422	1,458
	Average	.....	.....	.....	.....	.....	864	1,008	1,308	1,446	1,422
	1:4	.....	133-44	70.7	74.3	8.3	630	1,206	1,170	1,170	1,224
							630	990	1,242	1,152	1,188
							594	936	1,044	1,170	1,170
	Average	.....	.....	.....	.....	.....	618	1,044	1,152	1,164	1,194
	1:3 (sifted)	.....	133-45	72.5	74.6	8.9	666	882	918	1,170	1,044
							612	846	1,008	990	990
							612	792	972	954	1,008
	Average	.....	.....	.....	.....	.....	630	840	966	1,038	1,014
Se. 13..	1:3	1.04	133-46	70.7	72.5	9.1	864	1,098	1,260	1,422	1,458
							954	1,188	1,404	1,350	1,422
							900	1,188	1,440	1,296	1,512
	Average	.....	.....	.....	.....	.....	906	1,158	1,368	1,356	1,464
	1:4	.....	133-47	70.7	77.0	8.3	810	900	1,152	1,170	1,332
							774	828	1,152	1,260	1,296
							720	864	1,296	1,170	1,368
	Average	.....	.....	.....	.....	.....	768	864	1,200	1,200	1,332
	1:3 (sifted)	.....	134-1	72.4	78.8	8.9	684	972	918	1,008	1,170
							594	954	1,008	972	1,206
							666	792	1,080	1,080	1,080
	Average	.....	.....	.....	.....	.....	648	906	1,002	1,020	1,152
Se. 14..	1:3	1.07	134-2	77.0	78.8	8.9	1,044	1,008	1,314	1,278	.....
							864	.....	1,278	1,368	1,350
							936	1,062	1,332	1,368	1,404
	Average	.....	.....	.....	.....	.....	948	1,035	1,308	1,338	1,377
	1:4	.....	134-3	71.3	80.0	8.3	738	792	1,278	1,332	1,314
							720	828	1,098	1,224	1,296
							684	936	1,152	1,296	1,242
	Average	.....	.....	.....	.....	.....	714	852	1,176	1,284	1,284
	1:3 (sifted)	.....	134-4	76.1	74.8	8.9	792	918	810	990	1,116
							864	936	972	936	1,080
							972	.....	828	1,080	.....
	Average	.....	.....	.....	.....	.....	876	927	870	1,002	1,098

s.

78—Continued.

Register No.	Ratio of cement to screenings.				Air.	Water (per cent).	...ength (pounds per square inch).				
							7 days.	28 days.	90 days.	180 days.	360 days.
Se. 17..	1:3	1.13	134-5	75.2		8.9	792	1,026	1,152	1,098	1,188
							720	990	1,026	1,008	1,080
							612	900	1,062	936	1,134
	Average						708	972	1,080	1,014	1,134
	1:4		134-6	75.2	70.7	8.3	504	936	828	612	1,332
							540	954	918	576	810
							396	648	792	630	.....
	Average						480	846	846	006	1,071
	1:3 (sifted)		135-4	76.1	77.0	8.9	486	684	774	792	918
							522	702	828	792	846
							486	738	918	828	900
	Average						498	708	840	804	888
Se. 18..	1:3	1.06	134-8	76.1	77.0	8.9	702	918	1,224	1,368	.....
							774	774	1,260	1,440	1,440
							684	972	1,188	1,332	1,386
	Average						720	888	1,224	1,380	1,413
	1:4		134-9	75.2	80.6	8.3	594	666	1,188	1,332	1,332
							594	900	1,206	1,278	.....
							612	900	1,134	.....	.....
	Average						600	822	1,176	1,305	1,332
	1:3 (sifted)		134-10	75.2	78.8	8.9	738	1,062	1,224	1,278	1,440
							738	1,116	1,368	1,368	1,440
							828	1,260	1,242	1,386	1,476
	Average						768	1,146	1,278	1,344	1,452
Se 19..	1:3	1.06	135-1	78.8	82.4	8.9	918	1,260	1,530	1,368	1,674
							1,026	1,368	1,584	1,548	1,620
							990	1,314	1,656	1,764	.....
	Average						978	1,314	1,590	1,560	1,656
	1:4		135-2	77.0	76.1	8.3	828	1,278	1,350	1,332	1,134
							846	1,188	1,332	1,386	1,044
							756	1,188	1,206	1,350	1,098
	Average						810	1,218	1,299	1,356	1,098
	1:3 (sifted)		135-3	78.8	80.6	8.9	630	864	1,062	1,116	1,026
							540	846	1,044	1,080	1,116
							522	864	936	990	1,152
	Average						564	858	1,014	1,062	1,098

INDEX.

Page.

Acknowledgments to those donating 9, 42, 79, 92–93
Age, variation of strength with 1–2
Algonquin, Ill., sand from (No. 8), analysis of, diagram showing 54
sand from (No. 8), description of 46
mortar from, strength of 63, 69, 74
physical properties of 59, 60–61
plate showing 44
silt in. 77
uniformity coefficient of 78
Amherstburg, Ontario, gravel from (No. 9), analysis of, diagram showing ... 85
gravel from (No. 9), description of 84
mortar from, strength of 90, 92
physical properties of 59, 61
plate showing 84
silt in. 77
uniformity coefficient of 78
sand from (No. 16), analysis of, diagram showing. 54
description of 49
mortar from, strength of 65, 71, 76
physical properties of 59, 60–61
plate showing 50
silt in. 77
uniformity coefficient of 78
Analyses, granularmetric, curves of 53–54, 86–87, 106
curves of, figures showing 45, 48, 50, 52, 54, 81, 83, 85, 94, 96, 98, 100, 102, 105
making of 53, 86, 106
Armourdale, sand from (No. 2), analysis of, diagram showing 50
sand from (No. 2) description of 43–44
mortar from, strength of 62, 67, 73
physical properties of 59, 60–61
plate showing 40
silt in 77
uniformity coefficient of 78
Attica, Ind., gravel from (No. 11), analysis of, diagram showing 83
gravel from (No. 1) description of 85–86
mortar from, strength of 90, 92
physical properties of 59, 61
plate showing 86
silt in 77
uniformity coefficient of 78
gravel from (No. 12), analysis of, diagram showing 81
description of 86
mortar from, strength of 90, 92
physical properties of 59, 61
plate showing. 86
silt in. 77
uniformity coefficient of 78
sand from (No. 18), analysis of, diagram showing. 48
description of 49–50

Page.

Attica, Ind.—Continued.
sand from (No. 18)—Continued.
mortar from, strength of 66, 71
physical properties of 59, 60–61
plate showing. 50
silt in. 77
uniformity coefficient of 78
sand from (No. 19), analysis of, diagram showing 52
description of 50–51
mortar from, strength of 66, 72
physical properties of 59, 60–61
plate showing. 52
silt in. 77
uniformity coefficient of 78
sand from (No. 20), analysis of, diagram showing 52
description of. 51
mortar from, strength of 66, 72
physical properties of 59, 60–61
plate showing. 52
silt in. 77
uniformity coefficient of 78
Bonneterre, Mo., stone from No. 16), analysis of, diagram showing 96
stone from (No. 16) description of 101
mortar from, strength of 113, 119
physical properties of 60, 61
plate showing 102
silt in. 77
uniformity coefficient of 78
Carpenterville, Ill., sand from (No. 7), analysis of, diagram showing 48
sand from (No. 7) description of 45–46
mortar from, strength of 63, 69, 74
physical properties of 59, 60–61
plate showing 44
silt in. 77
uniformity coefficient of 78
Carthage, Ohio, gravel from (No. 5), analysis of, diagram showing 83
gravel from (No. 5), description of 82
mortar from, strength of 89, 91
physical properties of 59, 61
plate showing 82
silt in. 77
uniformity coefficient of 78
Casparis, Ohio, stone from (No. 23), analysis of, diagram showing 102
stone from (No. 23), description of 104
mortar from, strength of 115, 120
physical properties of 60, 61
plate showing 108
silt in 77
uniformity coefficient of 78
Cement, chemical tests of 10–12
compressive strength of 19–21, 24–26
variation of, with age .. 1, 25–26, 30–34, 37–38
diagram showing 26, 34, 39

Page.

Cement—Continued.
fineness of 13-15, 22
physical determinations of 12-42
making of, methods of 127
physical properties of 12-15
reports on 4
samples of, analyses of 10-12
mixing of 10
selection of 10
set of, time of 13-15, 22
specific gravity of 13-15, 22
temperature of 13-21
storage of, character of 8, 35-36
effects of 35-37
tensile strength of 16-18, 22-24, 33, 35-37
variation of, with age 1, 23-24, 26-29, 34
diagram showing 23, 34, 35
tests of 1, 9-42
methods of 9, 34
transverse strength of 39, 41-42
variation of, with age 1, 39, 41-42
diagram showing 40
volume of, change of 22
warping of 13-15, 22
water in, percentage of 13-15
Chert screenings, plate showing 98
Chilson, Mich., gravel from (No. 7), analysis of, diagram showing 85
gravel from (No. 7), description of 83-84
mortar from, strength of 90, 91
physical properties of 59, 61
plate showing 82
silt in 77
uniformity coefficient of 78
gravel from (No. 8) analysis of, diagram showing 85
description of 84
mortar from strength of 90, 92
physical properties of 59, 61
plate showing 84
silt in 77
uniformity coefficient of 78
sand from (No. 13) analysis of, diagram showing 54
description of 47
mortar from strength of 65, 70, 75
physical properties of 59, 60-61
plate showing 48
silt in 77
uniformity coefficient of 78
Cincinnati, sand near (No. 5) analysis of, diagram showing 50
sand near (No. 5), description of 44
mortar from, strength of 63, 68, 73
physical properties of 59, 60-61
plate showing 42
silt in 77
uniformity coefficient of 78
Columbus, Ohio, gravel from (No. 3), analysis of, diagram showing 85
gravel from (No. 3), description of 81-82
mortar from, strength of 89, 91
physical properties of 59, 61
plate showing 80
silt in 77
uniformity coefficient of 78

Page.

Columbus, Ohio—Continued.
sand from (No. 3), analysis of, diagram showing 52
description of 44
mortar from, strength of 62, 66, 73
physical properties of 59, 60-61
plate showing 40
silt in 77
uniformity coefficient of 78
stone from (No. 20) analysis of, diagram showing 102
description of 103
mortar from, strength of 114, 119
plate showing 106
silt in 77
uniformity coefficient of 78
Compression, tests by 8-9
Compressive strength, tests of 2, 8-9
See also Sand; Gravel; Stone.
Density relation of strength and 3
Desplaines River, sand from (No. 9), analysis of, diagram showing 52
sand from (No. 9), description of 46
mortar from, strength of 64, 69, 74
physical properties of 59, 60-61
plate showing 44
silt in 77
uniformity coefficient of 78
Drake, Mo., sand from (No. 22), analysis of, diagram showing 50
sand from (No. 22), description of 51-52
mortar from, strength of 67, 72, 76
physical properties of 59, 60-61
plate showing 54
silt in 77
uniformity coefficient of 78
Erie, Lake, gravel from (No. 10) analysis of, diagram showing 81
gravel from (No. 10), description of 84-85
mortar from, strength of 90, 92
physical properties of 59, 61
plate showing 84
silt in 77
uniformity coefficient of 78
Fox River, Ill. sand from (No. 6), analysis of, diagram showing 50
sand from (No. 6), description of 44-45
mortar from, strength of 63, 68, 74
physical properties of 59, 60-61
plate showing 42
silt in 77
uniformity coefficient of 78
sand from (No. 7), analysis of, diagram showing 48
description of 45-46
mortar from, strength of 63, 69, 74
physical properties of 59, 60-61
plate showing 44
silt in 77
uniformity coefficient of 78
sand from (No. 8), analysis of, diagram showing 54
description of 46
mortar from, strength of 63, 69, 74
physical properties of 59, 60-61

Page.
Fox River, Ill.—Continued.
sand from (No. 8)—Continued.
plate showing..... 44
silt in..... 77
uniformity coefficient of..... 78
Glencoe, Mo., stone from (No. 4), analysis of, diagram showing..... 105
stone from (No. 4), description of..... 95
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing..... 94
silt in..... 77
uniformity coefficient of..... 78
Granite screenings, plate showing..... 104
Graniteville, Mo., stone from (No. 17), analysis of, diagram showing..... 100
stone from (No. 17), description of..... 101
mortar from, strength of..... 113, 119, 124
physical properties of..... 60, 61
plate showing..... 104
silt in..... 77
uniformity coefficient of..... 78
Granularmetric analyses, curves of..... 53–54, 86–87, 106
curves of, figures showing..... 45, 48, 50, 52, 54, 81, 83, 85, 94, 96, 98, 100, 102, 105
making of..... 53, 86, 106
Gravel screenings, absorption percentage of. 59
collection of..... 80
density of..... 61, 79, 87
description of..... 80–86
granularmetric analysis of..... 86
curves of..... 79, 86–87
figures showing..... 81, 83, 85
physical properties of..... 59, 61, 79
physical tests of..... 3–4, 86–87
making of, method of..... 86
plates showing..... 54, 80, 82, 84, 86
silt in, analysis of..... 77
percentage of..... 59
specific gravity of..... 59
uniformity coefficients of..... 78, 87
weight of..... 59, 79
Gravel-screenings mortar, compressive strength of..... 79, 88, 91–92
compressive strength of, variation of, with age..... 91–92
density of..... 88–89
physical tests of..... 87–92
making of, method of..... 87–88
summary of..... 88
tensile strength of..... 79, 88, 89–90
variation of, with age..... 89–90
transverse strength of..... 79
uniformity coefficients of..... 78
Greenfield, Ohio, stone from (No. 22), analysis of, diagram showing..... 98
stone from (No. 22), description of..... 104
mortar from, strength of..... 114, 120
physical properties of..... 60, 61
plate showing..... 106
silt in..... 77
uniformity coefficient of..... 78
Hillsboro, Ohio, stone from (No. 21), analysis of, diagram showing..... 94
stone from (No. 21), description of... 103–104

Page.
Hillsboro, Ohio—Continued.
stone from (No. 21)—Continued.
mortar from, strength of..... 114
physical properties of..... 120
plate showing..... 106
silt in..... 77
uniformity coefficient of..... 78
Hoffman, Mo., stone from (No. 15), analysis of, diagram showing.....
stone from (No. 15), description of..... 101
mortar from, strength of..... 113, 118
physical properties of..... 60, 61
plate showing..... 102
silt in..... 77
uniformity coefficient of..... 78
Investigation, nature and extent of..... 7
Joplin, Mo., stone from (No. 6), analysis of, diagram showing..... 105
stone from (No. 6), description of..... 96–97
mortar from, strength of.... 111, 116, 121
physical properties of..... 60, 61
plate showing..... 96
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 7), analysis of, diagram showing..... 100
description of..... 97
mortar from, strength of.... 111, 117, 122
physical properties of..... 60, 61
plate showing..... 96
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 8), analysis of, diagram showing..... 100
description of..... 97
mortar from, strength of.... 111, 117, 122
physical properties of..... 60, 61
plate showing..... 98
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 9), analysis of, diagram showing..... 102
description of..... 97–98
mortar from, strength of..... 111, 117, 122
physical properties of..... 60, 61
plate showing..... 98
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 10), analysis of, diagram showing..... 100
description of..... 98–99
mortar from, strength of.... 112, 117, 122
physical properties of..... 60, 61
plate showing..... 98
silt in..... 77
uniformity coefficient of..... 78
Kankakee, Ill., stone from (No. 18), analysis of, diagram showing..... 98
stone from (No. 18), description of.... 101–103
mortar from, strength of..... 114, 119, 124
physical properties of..... 60, 61
plate showing..... 104
silt in..... 77
uniformity coefficient of..... 78
Kansas City, Mo., sand from (No. 1), analysis of, diagram showing..... 48

Page.
Kansas City, Mo.—Continued.
sand from (No. 1), description of..... 43
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60–61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78
Kansas City, Mo., stone from (No. 12), analysis of, diagram showing..... 96
stone from (No. 12) description of..... 99
mortar from, strength of..... 112, 118, 123
physical properties of..... 60, 61
plate showing..... 100
silt in..... 77
uniformity coefficient of..... 78
Kansas River, sand from (No. 2), analysis of, diagram showing..... 50
sand from (No. 2), description of..... 43–44
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60–61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78
Kentucky, Kenton County, sand from (No. 10), analysis of, diagram showing..... 45
Kenton County, sand from (No. 10), description of..... 46–47
sand from (No. 10), mortar from, strength of..... 64–69
physical properties of..... 59, 60–61
plate showing..... 46
silt in..... 77
uniformity coefficient of..... 78
Libertyville, Ill., sand from (No. 9), analysis of, diagram showing..... 52
sand from (No. 9), description of..... 46
mortar from, strength of..... 64, 69, 74
physical properties of..... 59, 60–61
plate showing..... 44
silt in..... 77
uniformity coefficient of..... 78
Limestone screenings, plates showing..... 94
96, 100, 102, 104, 108
Lorain, Ohio, gravel from (No. 10), analysis of, diagram showing..... 81
gravel from (No. 10) description of..... 84–85
mortar from, strength of..... 90, 92
physical properties of..... 59, 61
plate showing..... 84
silt in..... 77
uniformity coefficient of..... 78
Loveland, Ohio, gravel from (No. 4), analysis of, diagram showing..... 81
gravel from (No. 4), description of..... 82
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
Ludlow, Ky., gravel from (No. 6), analysis of, diagram showing..... 83
gravel from (No. 6), description of..... 82–83
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 82
silt in..... 77
uniformity coefficient of..... 78
Page.
McCook, Ill., stone from (No. 19), analysis of, diagram showing..... 94
stone from (No. 19), description of..... 103
mortar from, strength of..... 114, 119, 124
physical properties of..... 60, 61
plate showing..... 104
silt in..... 77
uniformity coefficient of..... 78
Meramec River, gravel from (No. 1), analysis of, diagram showing..... 83
gravel from (No. 1), description of..... 80
mortar from, strength of..... 81, 89
physical properties of..... 59, 61
plate showing..... 54
silt in..... 77
uniformity coefficient of..... 78
gravel from (No. 2), analysis of, diagram showing..... 81
description of..... 80
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 21), analysis of, diagram showing..... 45
description of..... 51
mortar from, strength of..... 67, 72
physical properties of..... 59, 60–61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 22), analysis of, diagram showing..... 50
description of..... 51–52
mortar from, strength of..... 67, 72
physical properties of..... 59, 60–61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78
Missouri Buchanan County, stone from (No. 13), analysis of, diagram showing..... 98
Buchanan County, stone from (No. 13), description of..... 99
stone from (No. 3) mortar from, strength of..... 112, 118, 123
physical properties of..... 60, 61
plate showing..... 100
silt in..... 77
uniformity coefficient of..... 78
Jackson County stone from (No. 14), analysis of, diagram showing..... 102
stone from (No. 14), description of..... 99–100
mortar from strength of..... 113, 118, 123
physical properties of..... 60, 61
plate showing..... 102
silt in..... 77
uniformity coefficient of..... 78
Missouri River, sand from (No. 1), analysis of, diagram showing..... 48
sand from (No. 1), description of..... 43
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60–61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78

Page.

Monroe formation, sand from (No. 11), analysis of, diagram showing.. 52
sand from (No. 11), description of..... 47
mortar from, strength of..... 64, 70, 75
physical properties of..... 59, 60–61
plate showing.. 46
silt in. 77
uniformity coefficient of..... 78
sand from (No. 12), analysis of, diagram showing..... 54
description of..... 47
mortar from, strength of..... 64, 70, 75
physical properties of.. ..... 59, 60–61
plate showing 46
silt in 77
uniformity coefficient of..... 78

Morsches Spur Bar, Mo., gravel from (No. 1), analysis of, diagram showing.. 83
gravel from (No. 1), description of..... 80
mortar from, strength of..... 89, 91
physical properties of..... 59–61
plate showing.. 54
silt in. 77
uniformity coefficient of..... 78

Mortar, strength of, determination of..... 7–8

Moselle, Mo., gravel from (No. 2), analysis of, diagram showing..... 81
gravel from (No. 2), description of..... 80
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 21) analysis of, diagram showing. 45
description of. 51
mortar from, strength of..... 67, 72
physical properties of..... 59, 60–61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78

Ohio River sand from (No. 5) analysis of, diagram showing. 50
sand from (No. 5) description of..... 44
mortar from, strength of..... 63, 68, 73
physical properties of..... 59, 60–61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78

Ottawa, Ill., sand from, description of.... 52
sand from, plate showing. 54

Register numbers, explanation of..... 8

St. Charles, Ill., sand from (No. 6), analysis of, diagram showing..... 50
sand from (No. 6), description of..... 44–45
mortar from, strength of..... 63, 68, 74
physical properties of..... 59, 60–61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78

St. Clair River, Ontario, gravel from (No. 9), analysis of, diagram showing..... 85

St. Clair River, Ontario—Continued.
gravel from (No. 9), description of 84
mortar from, strength of..... 90, 92
physical properties of..... 59, 61
plate showing..... 84
silt in..... 77
uniformity coefficient of..... 78
sand from, (No. 14), analysis of, diagram showing. 48
description of. 47–48
mortar from, strength of..... 65, 70, 75
physical properties of..... 59, 60–61
plate showing..... 48
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 15), analysis of, diagram showing..... 45
description of. 49
mortar from, strength of..... 65, 71, 75
physical properties of..... 59, 60–61
plate showing..... 48
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 16), analysis of, diagram showing. 54
description of..... 49
mortar from, strength of..... 65, 71, 76
physical properties of..... 59, 60
plate showing 50
silt in..... 77
uniformity coefficient of..... 78

St. Louis, stone from (No.), analysis of, diagram showing 96
stone from (No. 1) description of..... 93
mortar from, strength of..... 109, 115
physical properties of..... 60, 61
plate showing..... 86
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 2), analysis of, diagram showing..... 69
description of..... 93–94
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing. 94
silt in. 77
uniformity coefficient of..... 78
stone from (No. 3), analysis of, diagram showing..... 94
description of 94–95
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing. 94
silt in. 77
uniformity coefficient of..... 78
stone near (No. 11) analysis of, diagram showing..... 94
description of 99
mortar from, strength of..... 112, 117, 123
physical properties of..... 60, 61
plate showing. 100
silt in 77
uniformity coefficient of..... 78

Sand, absorption percentage of..... 59
collection of..... 42–43

Page.

Sand—Continued.
density of..... 55, 59–60, 78
description of..... 42–52
granularmetric analysis of..... 53
curves of..... 53–55, 78
figures showing..... 45, 48, 50, 52, 54
physical properties of..... 59–61, 78
physical tests of..... 53–56
making of, method of..... 53
plates showing..... 40, 42, 44, 46, 48, 50, 52, 54
silt in, analysis of..... 77
per cent of..... 59
specific gravity of..... 59
uniformity coefficients of..... 55–56, 78
weight of..... 59
Sand mortar, compressive strength of. 57, 67–72, 78
compressive strength of, variation of, with age..... 1–2, 25–26, 32–34
variation of, with age, diagram showing..... 27, 34
density of..... 3, 58–59, 60–61, 78
physical tests of..... 1–2, 56–79
making of, method of..... 56–57
summary of..... 57–58
tensile strength of..... 57, 62–67, 78
variation of, with age..... 24, 29–30, 34
diagram showing..... 24, 34
transverse strength of..... 57, 73–76, 78
Scioto River, Ohio, gravel from (No. 3), analysis of, diagram showing..... 85
gravel from (No. 3), description of..... 81–82
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 3), analysis of, diagram showing..... 52
description of..... 44
mortar from, strength of..... 62, 68, 73
physical properties of..... 59, 60–61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78
Sibley, Mich., stone from (No. 25), analysis of, diagram showing..... 98
stone from (No. 25), description of..... 106
mortar from, strength of..... 115, 120
physical properties of..... 60, 61
plate showing..... 108
silt in..... 77
uniformity coefficient of..... 78
Springfield, Mo., stone from (No. 5), analysis of, diagram showing..... 105
stone from (No. 5), description of..... 95
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing..... 96
silt in..... 77
uniformity coefficient of..... 78
Stone, strength of, report on..... 4–5
Stone screenings, absorption percentage of.. 60
collection of..... 93

Page.

.... 61, 79, 106–107
..... 93–106
ularmetric analysis of..... 106
curves of..... 79, 106
figures showing.. 94, 96, 98, 100, 102, 105
sical properties of..... 60, 61, 79
sical test of..... 106–107
making of, method of..... 106
es showing... 94, 96, 98, 100, 102, 104, 106, 108
n, analysis of..... 77
percentage of..... 60
ific gravity of..... 60
ht of..... 60, 79
Stone-screenings mortar, compressive strength of..... 79, 108, 115–120
pressive strength of, variation of, with age..... 115–120
ity of..... 109
sical tests of..... 107–123
making of, method of..... 107
summary of..... 108–109
ile strength of..... 79, 107–108, 109–115
variation of, with age..... 109–115
nsverse strength of..... 4, 79, 108, 121–123
variation of, with age..... 121–124
Storage, character of..... 8
Strength, tests of..... 8
ation of, with age. *See* Cement; Sand mortar; Gravel-screenings mortar; Stone-screenings mortar.
Sylvania, Ohio, stone from (No. 24), analysis of, diagram showing..... 105
stone from (No. 24), description of.... 104–106
mortar from, strength of..... 115, 120
physical properties of..... 60, 61
plate showing..... 108
silt in..... 77
uniformity coefficient of..... 78
Symmes, Ohio, sand from (No. 4), analysis of, diagram showing..... 54
sand from (No. 4), description of..... 44
mortar from, strength of..... 62, 68, 73
physical properties of..... 59, 60–61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78
Tensile strength, tests of..... 1–2, 8
See also Sand; Gravel; Stone.
Tension, tests by..... 8
Tests, character of..... 8
Transverse strength, tests of..... 9
See also Sand; Gravel; Stone.
Utica, Mich., sand from (No. 17), analysis of, diagram showing..... 45
sand from (No. 17), description of..... 49
mortar from, strength of..... 66, 71, 76
physical properties of..... 59, 60–61
plate showing..... 50
silt in..... 77
uniformity coefficient of..... 78
Voids, relation of strength and..... 3

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 331.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hyrographic progress reports; Q, Fuels; R, Structural materials. This paper is the third in Series R, the complete list of which follows (B=Bulletin):

SERIES R, STRUCTURAL MATERIALS.

B 324. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials; reports by G. K. Gilbert, R. L. Humphrey, J. S. Sewell, and Frank Soulé, with preface by J. A. Holmes. 1907. 170 pp., 57 pls.

B 329. Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo., by R. L. Humphrey. 1908. 85 pp., 25 pls.

B 331. Portland-cement mortars and their constituent materials; results of tests made at the structural-materials testing laboratories, Forest Park, St. Louis, Mo., 1905–1907, by R. L. Humphrey. 1908. 130 pp., 20 pls.

Correspondence should be addressed to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

FEBRUARY, 1908.

O

Bulletin No. 332

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

REPORT

OF THE

UNITED STATES FUEL-TESTING PLANT, AT ST. LOUIS, MO.

JANUARY 1, 1906, TO JUNE 30, 1907

JOSEPH A. HOLMES
IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

CONTENTS.

	Page.
Introduction, by J. A. Holmes	5
Work done	5
The outlook for future work	9
Abbreviations	11
Field work, by Edward W. Parker and J. Shober Burrows	12
Introduction	12
Personnel	12
Designation of samples	12
Samples received and tested	13
Work of the chemical laboratory, by N. W. Lord	20
Introduction	20
Equipment	20
Changes in analytical methods	20
Personnel	21
Work of the laboratory	21
Steaming tests, by L. P. Breckenridge	22
Equipment	22
Personnel	22
Coals tested	23
General results	24
Producer-gas tests, by Robert H. Fernald	25
Equipment	25
Personnel	25
Regular and special test conditions	26
Coals tested	27
Summary	27
Washing tests, by G. R. Delamater	29
Introduction	29
Equipment and operation	29
Explanation of the washing-test data	30
Coals tested	31
Coking tests, by A. W. Belden	32
Introduction	32
Coals tested	32
Future work	33
Cupola tests on coke, by Richard Moldenke	34
Equipment	34
Personnel	34
Method of testing	34
Cokes tested	35
Briquetting tests, by C. T. Malcolmson	36
Introduction	36

Page.
Kansas City, Mo.—Continued.
sand from (No. 1), description of..... 43
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60-61
plate showing 40
silt in..... 77
uniformity coefficient of..... 78
Kansas City Mo., stone from (No. 12), analysis of, diagram showing..... 96
stone from (No. 12), description of..... 99
mortar from, strength of..... 112, 118, 123
physical properties of..... 60, 61
plate showing..... 100
silt in..... 77
uniformity coefficient of..... 78
Kansas River, sand from (No. 2), analysis of, diagram showing..... 50
sand from (No. 2), description of..... 43-44
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60-61
plate showing 40
silt in..... 77
uniformity coefficient of..... 78
Kentucky, Kenton County sand from (No. 10), analysis of, diagram showing 45
Kenton County, sand from (No. 10), description of..... 46-47
sand from (No. 10), mortar from, strength of..... 64-69
physical properties of..... 59, 60-61
plate showing..... 46
silt in..... 77
uniformity coefficient of..... 78
Libertyville, Ill., sand from (No. 9) analysis of, diagram showing..... 52
sand from (No. 9) description of..... 46
mortar from, strength of..... 64, 69, 74
physical properties of..... 59, 60-61
plate showing 44
silt in 77
uniformity coefficient of..... 78
Limestone screenings, plates showing..... 94
96, 100, 102, 104, 108
Lorain, Ohio, gravel from (No. 10), analysis of, diagram showing..... 81
gravel from (No. 10), description of..... 84-85
mortar from, strength of..... 90, 92
physical properties of..... 59, 61
plate showing 84
silt in 77
uniformity coefficient of..... 78
Loveland, Ohio, gravel from (No. 4), analysis of diagram showing..... 81
gravel from (No. 4), description of..... 82
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing 80
silt in..... 77
uniformity coefficient of..... 78
Ludlow, Ky gravel from (No. 6), analysis of, diagram showing..... 83
gravel from (No. 6), description of..... 82-83
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 82
silt in..... 77
uniformity coefficient of..... 78
McCook, Ill., stone from (No. 19), analysis of, diagram showing..... 94
stone from (No. 19), description of..... 103
mortar from, strength of..... 114, 119, 124
physical properties of..... 60, 61
plate showing..... 104
silt in 77
uniformity coefficient of..... 78
Meramec River, gravel from (No. 1), analysis of, diagram showing..... 83
gravel from (No. 1) description of..... 80
mortar from, strength of..... 81, 80
physical properties of..... 59, 61
plate showing..... 84
silt in 77
uniformity coefficient of..... 78
gravel from (No. 2) analysis of, diagram showing..... 81
description of..... 80
mortar from, strength of..... 80, 91
physical properties of 59, 61
plate showing 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 21), analysis of, diagram showing..... 45
description of..... 51
mortar from, strength of..... 67, 72
physical properties of..... 59, 60-61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 22), analysis of, diagram showing..... 50
description of..... 51-52
mortar from, strength of..... 67, 72
physical properties of..... 59, 60-61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78
Missouri Buchanan County, stone from (No. 13), analysis of, diagram showing 98
Buchanan County, stone from (No. 13), description of..... 99
stone from (No. 13), mortar from, strength of..... 112, 118, 123
physical properties of..... 60, 61
plate showing..... 100
silt in..... 77
uniformity coefficient of..... 78
Jackson County stone from (No. 14), analysis of, diagram showing..... 102
stone from (No. 14), description of. 99-100
mortar from, strength of. 113, 118, 123
physical properties of..... 60, 61
plate showing..... 102
silt in..... 77
uniformity coefficient of..... 78
Missouri River sand from (No. , analysis of, diagram showing..... 48
sand from (No. 1) description of..... 43
mortar from, strength of..... 62, 67, 73
physical properties of..... 59, 60-61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78

Page.

Monroe formation, sand from (No. 11), analysis of, diagram showing.. 52
sand from (No. 11), description of..... 47
mortar from, strength of..... 64, 70, 75
physical properties of..... 59, 60–61
plate showing..... 46
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 12), analysis of, diagram showing..... 54
description of..... 47
mortar from, strength of..... 64, 70, 75
physical properties of..... 59, 60–61
plate showing..... 46
silt in..... 77
uniformity coefficient of..... 78

Morsches Spur Bar, Mo., gravel from (No. 1), analysis of, diagram showing.. 83
gravel from (No. 1), description of..... 80
mortar from, strength of..... 89, 91
physical properties of..... 59–61
plate showing..... 54
silt in..... 77
uniformity coefficient of..... 78

Mortar, strength of, determination of..... 7–8

Moselle, Mo., gravel from (No. 2), analysis of, diagram showing..... 81
gravel from (No. 2), description of..... 80
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 21), analysis of, diagram showing..... 45
description of..... 51
mortar from, strength of..... 67, 72
physical properties of..... 59, 60–61
plate showing..... 52
silt in..... 77
uniformity coefficient of..... 78

Ohio River sand from (No. 5), analysis of, diagram showing..... 50
sand from (No. 5), description of..... 44
mortar from, strength of..... 63, 68, 73
physical properties of..... 59, 60–61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78

Ottawa, Ill., sand from, description of.... 52
sand from, plate showing..... 54

Register numbers, explanation of..... 8

St. Charles, Ill. sand from (No. 6), analysis of, diagram showing..... 50
sand from (No. 6), description of..... 44–45
mortar from, strength of..... 63, 68, 74
physical properties of..... 59, 60–61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78

St. Clair River, Ontario, gravel from (No. 9), analysis of, diagram showing..... 85

St. Clair River, Ontario—Continued.
gravel from (No. 9), description of..... 84
mortar from, strength of..... 90, 92
physical properties of..... 59, 61
plate showing..... 84
silt in..... 77
uniformity coefficient of..... 78
sand from, (No. 14) analysis of, diagram showing..... 48
description of..... 47–48
mortar from, strength of..... 65, 70, 75
physical properties of..... 59, 60–61
plate showing..... 48
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 15) analysis of, diagram showing..... 45
description of..... 49
mortar from, strength of..... 65, 71, 75
physical properties of..... 59, 60–61
plate showing..... 48
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 16) analysis of, diagram showing..... 54
description of..... 49
mortar from, strength of..... 65, 71, 76
physical properties of..... 59, 60
plate showing..... 50
silt in..... 77
uniformity coefficient of..... 78

St. Louis, stone from (No. analysis of, diagram showing..... 96
stone from (No. 1), description of..... 93
mortar from, strength of..... 109, 115
physical properties of..... 60, 61
plate showing..... 86
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 2), analysis of, diagram showing..... 69
description of..... 93–94
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing..... 94
silt in..... 77
uniformity coefficient of..... 78
stone from (No. 3), analysis of, diagram showing..... 94
description of..... 94–95
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing..... 94
silt in..... 77
uniformity coefficient of..... 78
stone near (No. analysis of, diagram showing..... 94
description of..... 99
mortar from, strength of..... 112, 117, 123
physical properties of..... 60, 61
plate showing..... 100
silt in..... 77
uniformity coefficient of..... 78

Sand, absorption percentage of..... 59
collection of..... 42–43

Page.

Sand—Continued.
density of..... 55, 59-60, 78
description of..... 43-52
granularmetric analysis of..... 53
curves of..... 53-55, 78
figures showing..... 45, 48, 50, 52, 54
physical properties of..... 59-61, 78
physical tests of..... 53-56
making of, method of..... 53
plates showing..... 40, 42, 44, 46, 48, 50, 52, 54
silt in, analysis of..... 77
per cent of..... 59
specific gravity of..... 59
uniformity coefficients of..... 55-56, 78
weight of..... 59
Sand mortar, compressive strength of. 57, 67-72, 78
compressive strength of, variation of, with age..... 1-2, 25-26, 32-34
variation of, with age, diagram showing..... 27, 34
density of..... 3, 58-59, 60-61, 78
physical tests of..... 1-2, 56-79
making of, method of..... 56-57
summary of..... 57-58
tensile strength of..... 57, 62-67, 78
variation of, with age..... 24, 29-30, 34
diagram showing..... 24, 34
transverse strength of..... 57, 73-76, 78
Scioto River, Ohio, gravel from (No. 3), analysis of, diagram showing..... 85
gravel from (No. 3), description of..... 81-82
mortar from, strength of..... 89, 91
physical properties of..... 59, 61
plate showing..... 80
silt in..... 77
uniformity coefficient of..... 78
sand from (No. 3), analysis of, diagram showing..... 52
description of..... 44
mortar from, strength of..... 62, 68, 73
physical properties of..... 59, 60-61
plate showing..... 40
silt in..... 77
uniformity coefficient of..... 78
Sibley, Mich., stone from (No. 25), analysis of, diagram showing..... 98
stone from (No. 25), description of..... 106
mortar from, strength of..... 115, 120
physical properties of..... 60, 61
plate showing..... 108
silt in..... 77
uniformity coefficient of..... 78
Springfield, Mo., stone from (No. 5), analysis of, diagram showing..... 105
stone from (No. 5), description of..... 95
mortar from, strength of..... 110, 116, 121
physical properties of..... 60, 61
plate showing..... 96
silt in..... 77
uniformity coefficient of..... 78
Stone, strength of, report on..... 4-5
Stone screenings, absorption percentage of.. 60
collection of..... 93

Page.

Stone screenings—Continued.
density of..... 61, 79, 106-107
description of..... 93-106
granularmetric analysis of..... 106
curves of..... 79, 106
figures showing.. 94, 96, 98, 100, 102, 105
physical properties of..... 60, 61, 79
physical test of..... 106-107
making of, method of..... 106
plates showing... 94, 96, 98, 100, 102, 104, 106, 108
silt in, analysis of..... 77
percentage of..... 60
specific gravity of..... 60
weight of..... 60, 79
Stone-screenings mortar, compressive strength of..... 79, 108, 115-120
compressive strength of, variation of, with age..... 115-120
density of..... 109
physical tests of..... 107-123
making of, method of..... 107
summary of..... 108-109
tensile strength of..... 79, 107-108, 109-115
variation of, with age..... 109-115
transverse strength of..... 4, 79, 108, 121-123
variation of, with age..... 121-124
Storage, character of..... 8
Strength, tests of..... 8
variation of, with age. *See* Cement; Sand mortar; Gravel-screenings mortar; Stone-screenings mortar.
Sylvania, Ohio, stone from (No. 24), analysis of, diagram showing..... 105
stone from (No. 24), description of.... 104-106
mortar from, strength of..... 115, 120
physical properties of..... 60, 61
plate showing..... 108
silt in..... 77
uniformity coefficient of..... 78
Symmes, Ohio, sand from (No. 4), analysis of, diagram showing..... 54
sand from (No. 4), description of..... 44
mortar from, strength of..... 62, 68, 73
physical properties of..... 59, 60-61
plate showing..... 42
silt in..... 77
uniformity coefficient of..... 78
Tensile strength, tests of..... 1-2, 8
See also Sand; Gravel; Stone.
Tension, tests by..... 8
Tests, character of..... 8
Transverse strength, tests of..... 9
See also Sand; Gravel; Stone.
Utica, Mich., sand from (No. 17), analysis of, diagram showing..... 45
sand from (No. 17), description of..... 49
mortar from, strength of..... 66, 71, 76
physical properties of..... 59, 60-61
plate showing..... 50
silt in..... 77
uniformity coefficient of..... 78
Voids, relation of strength and..... 3

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 331.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hyrographic progress reports; Q, Fuels; R, Structural materials. This paper is the third in Series R, the complete list of which follows (B=Bulletin):

SERIES R, STRUCTURAL MATERIALS.

B 324. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials; reports by G. K. Gilbert, R. L. Humphrey, J. S. Sewell, and Frank Soulé, with preface by J. A. Holmes. 1907. 170 pp., 57 pls.

B 329. Organization, equipment, and operation of the structural-materials testing laboratories at St. Louis, Mo., by R. L. Humphrey. 1908. 85 pp., 25 pls.

B 331. Portland-cement mortars and their constituent materials; results of tests made at the structural-materials testing laboratories, Forest Park, St. Louis, Mo., 1905-1907, by R. L. Humphrey. 1908. 130 pp., 20 pls.

Correspondence should be addressed to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

FEBRUARY, 1908.

O

Bulletin No. 332

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

REPORT

OF THE

UNITED STATES FUEL-TESTING PLANT, AT ST. LOUIS, MO.

JANUARY 1, 1906, TO JUNE 30, 1907

JOSEPH A. HOLMES
IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

The principal chemical laboratory of the fuel-testing plant has been removed to Pittsburg, and to it will be sent all fuel samples for analysis, including briquets, coke, etc. At this laboratory will be conducted an exhaustive series of investigations into the most efficient methods of using, for coke and other purposes, the coals and lignites belonging to the Government of the United States, and the by-products of coke, with a view to determining methods for their utilization. A branch chemical and physical laboratory will be maintained at the Norfolk fuel-testing plant for the purpose of experimenting on the gases in different portions of the combustion chambers of steam boilers and of gas producers, analyses to be made of the gases at high temperatures, and the highest temperatures to be measured. It is expected that the results of these investigations may have an important bearing on the methods of construction of combustion chambers and the relation of the heat-transmitting surfaces to the fuel bed. Routine chemical work will be conducted as heretofore at the fuel-testing plants for analyses of samples, including gas and other products of combustion. A special investigation will be undertaken to ascertain the nature of cokes made from different coals, with a view to determining why good coke can be made from one coal and not from another. Field investigations will be made with a view to studying the coals where found, and later these investigations will be continued in the laboratories at Washington.

The smoke-abatement investigations at public buildings will be supplemented by more detailed experiments along the same lines at the Norfolk plant, where different methods of handling the two Heine boilers and the new 250-horsepower Babcock & Wilcox water-tube boiler will be attempted. One of these boilers will be hand fired, one fired with mechanical overfeed, and one with a mechanical underfeed stoker. All three are equipped for natural draft, for forced draft, and for induced draft, and it is believed that it will be possible to show just how each type of fuel should be burned in order to secure the highest efficiency, which means the complete combustion of all of the carbon and the abatement of smoke. This investigation is conducted with special reference to the needs of power and heating plants in the Government buildings in the different cities of the country.

The gas producer will be run on prolonged tests with a view to determining along commercial lines the fuel values through the gas engine of the various fuels tested; also with a view to determining the possibility of utilizing the different classes of fuel through the gas producer for naval purposes.

The investigation of coal waste at the mines is being extended with a view to determining how far such waste is due to improper methods of mining, especially to the improper use of explosives or to the use of improper explosives. Investigations are also being made to discover

the extent to which less wasteful methods of mining may be introduced without excessive cost to the operators. (See p. 9.)

Under the wording of the act of Congress providing for the continuation of the work to June 30, 1908, the technologic branch is engaged in revising the purchases of coals for the Government, with a view to adopting better methods of making such purchases, especially in regard to specifications which shall consider the ash contained and the heating units in the coal. This branch is also engaged in investigating and reporting on explosives and other materials used by the Reclamation Service and in the Panama Canal. To it has recently been transferred the mine inspection in the Territories, and this part of the work of Federal mine inspection will receive particular attention during the coming year.

ABBREVIATIONS.

The following abbreviations are used in the report:

B. t. u. =British thermal units.
cr. =crushed.
c. t. p. =coal-tar pitch.
e. h. p. =electrical horsepower.
Eng. =English (briquetting machine).
f. c. =finely crushed.
Lab. No. =chemical laboratory number.
l. =lump.
Renf. =Renfrow (briquetting machine).
r. o. m. =run of mine.
r. p. m. =revolutions per minute.
s. =slack.
sc. =screenings.
w. =washed.
w. g. p. =water-gas pitch.
* =briquets used in locomotive test (see p. 42).
† =briquets used in house-boiler test (see p. 42).

FIELD WORK.

By Edward W. Parker and J. Shober Burrows

INTRODUCTION.

The conditions for submitting coal to be tested and the methods of inspecting the mine and obtaining mine supplies were the same for the period covered by this report as during the year 1905.[a]

PERSONNEL.

John W. Groves and William J. Von Borries inspected and shipped most of the samples until March, 1906, when Mr. Von Borries resigned. From March until July all the samples were shipped by Messrs. Burrows and Groves, with the exception of three from the State of Washington, which were secured by M. R. Campbell, of the geologic branch. At the beginning of the fiscal year, July 1, 1906, Mr. Parker was relieved of his duties in connection with this work and Mr. Burrows, who had directed the field work under Mr. Parker's supervision, was placed in full charge of the corps of inspectors. During the summer and autumn F. B. Tough and A. K. Adams were employed for a few months, and K. M. Way and R. T. Carroll joined the corps of inspectors during this period. N. H. Darton, of the geologic branch, cooperated with the technologic branch in procuring samples from Montana.

DESIGNATION OF SAMPLES.

When the sample or car of coal is shipped it is marked with the name of the State in which the mine is situated and numbered consecutively in the order of shipment, the numbers for 1906 beginning where those for 1905 left off. When two or three cars or lots constituting different grades of coal, such as lump, nut, etc., are shipped from a mine, each lot is designated by a letter. For example, Illinois No. 23 A, the first shipment, is lump coal, and Illinois No. 23 B is slack coal taken from the same mine.

[a] See Bull. U. S. Geol. Survey No. 290, 1906, p. 16.

SAMPLES RECEIVED AND TESTED.

During the period covered by this report 137 samples from 24 States and Territories and 1 sample from Argentina were received and tested.

The following is a complete list of the carload samples received, with the details of the location of the bed, character of the samples, inspector, and page references for all the tests made on these fuels during the period here included:

Samples of fuels received and tests made, by States.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Alabama:														
No. 2 B	Bituminous; run of mine	Jagger	Carbon Hill	Walker	Frisco	J. S. Burrows	47	47	48	....	48	48	49	49
No. 3	do	Underwood or Thompson.	Garnsey	Bibb	Louisville and Nashville.	J. W. Groves	50	50	51	....	51	51	52	....
No. 4	do	Youngblood	Belle Ellen	do	do	do	52	53	53	54	54	54	55	56
No. 5	do	Black Creek	Lehigh	Blount	do	do	56	57	57	....	57	58	....	....
No. 6	do	Pratt	Dolomite	Jefferson	do	K. M. Way	58	58	59	59	60	60	....	....
Argentina No. 1				Province of Mendoza.		Uninspected	61	61	62	....	62	....	....	63
Arkansas:														
No. 1 B	Bituminous; slack	Huntington	Huntington	Sebastian	Frisco	J. W. Groves	63	64	....	....	64	64	65	....
No. 7 A	Bituminous; lump, over 2-inch perforated screen.	Hartshorne	Midland (4 miles southwest).	do	Midland Valley	do	65	66	66	67	....	....	....	....
No. 7 B	Bituminous; slack, through 2-inch perforated screen.	do	do	do	do	do	65	66	....	....	67	67	68	69
No. 8	Semianthracite; size 4, through 1¼-inch round perforated screen.	(?)	Spadra	Johnson	St. Louis, Iron Mountain and Southern.	W. J. Von Borries	69	69	70	70	71	....	....	....
No. 9	Bituminous; slack, through 1¼-inch bar screen.	Huntington	Bonanza	Sebastian	Frisco	J. W. Groves	71	71	....	....	71	71	72	....
No. 10	Lignite; run of mine	(?)	Lester (7 miles west).	Ouachita	St. Louis, Iron Mountain and Southern.	do	73	73	73	74	....	....	....	....
No. 13	Bituminous; slack	(?)	Denning	Franklin	do	Uninspected	74	75	....	....	....	....	....	....
Florida No. 1	Machined peat		Orlando	Orange	Seaboard	J. S. Burrows	76	77	77	77	....	....	....	....
Georgia No. 1	Bituminous; lump, over 1½-inch perforated stationary screen.	Little River	Menlo	Chattooga	Chattanooga Southern.	A. K. Adams	78	78	79	....	....	79	....	....
Illinois:														
No. 7 E	Bituminous; screened nut	No. 6	Collinsville	Madison	Vandalia	Uninspected	79	80	80	....	....	....	....	80
No. 9 C	Bituminous; slack	do	Staunton	Macoupin	Litchfield and Madison.	do	81	81	81	....	....	....	....	82

No. 12 B	Bituminous; size 5	do	Bush	Williamson	St. Louis, Iron Mountain and Southern.	do	83	83	83					84
No. 19 C	Bituminous; run of mine	No. 7	Ziegler	Franklin	Illinois Central	J. W. Groves	85	85	85	86				
No. 19 D	Bituminous; lump, over 6-inch shaking screen.	do	do	do	do	do	85	85	85					
No. 19 E	Bituminous; through 1½-inch shaking screen.	do	do	do	do	do	85	85	85					
No. 20	Bituminous; screenings	No. 6	Staunton	Macoupin	Litchfield and Madison.	Uninspected	87	87	87		88	88		88
No. 21	Bituminous; lump, over 2½-inch screen.	do	Troy	Madison	St. Louis, Troy and Eastern.	J. W. Groves	89	89	89	90	91	91		91
No. 22 A	Bituminous; lump, over 4-inch perforated shaking screen.	do	Marysville	do	do	do	91	92	92	93	93			
No. 22 B	Bituminous; nut, pea, and slack, through 2-inch perforated screen.	do	do	do	do	do	91	92			93	93	94	
No. 23 A	Bituminous; lump, over 5-inch perforated screen.	do	Donkville	do	do	do	94	95	95	96	96	97		
No. 23 B	Bituminous; slack, through 2-inch perforated screen.	do	do	do	do	do	94	95	95	96	96	97		97
No. 24 A	Bituminous; screenings, through 2½-inch shaking screen.	do	New Baden	Clinton	Southern	W. J. Von Borries	97	98			99	99		
No. 24 B	Bituminous; lump, over 5½-inch bar screen.	do	do	do	do	do	97	98	98	99	99	99		
No. 25 A	Bituminous; run of mine	do	Germantown	do	do	J. W. Groves	100	100	101		102	102		
No. 25 B	Bituminous; lump, over 1¾-inch screen.	do	do	do	do	do	100	100	101	101				
No. 26	Bituminous; run of mine	No. 5	Lincoln	Logan	Chicago and Alton.	do	102	103	103	104	104	104		
No. 27	do	No. 6	Auburn	Sangamon	do	do	104	105	105	106	106	106		
No. 28 A	Bituminous; size 5, washed	No. 7	Herrin	Williamson	Illinois Central	Uninspected	107	107	108					109
No. 28 B	Bituminous; screenings, raw	do	do	do	do	do	107	107	108					109
No. 28 C	Bituminous; lump, over 3-inch round shaking screen.	do	do	do	do	K. M. Way	107	107	108		108	108		
No. 29 A	Bituminous; screenings, through 2-inch shaking screen.	No. 5	Livingston	Madison		do	110	111	111		112	112	113	114
No. 29 B	Bituminous; run of mine	do	do	do		do	110	111	111	112				114
No. 30	Bituminous; nut, through 3-inch and over 2-inch shaking screen.	No. 7	Shiloh	St. Clair	Southern	do	115	115	116	116	117			117
No. 31	Bituminous; screenings, over 1¼-inch shaking screen.	No. 6	Warden	do	Wabash	do	118	119	119					119
No. 33	Bituminous; screenings, through 1½-inch shaking screen.	No. 7	Trenton	Clinton	Baltimore and Ohio.	do	120	121	121					121
No. 34 A	Bituminous; screenings, over 1¼-inch shaking screen.	No. 5	Harrisburg	Saline	Big Four	do	122	123			123			
No. 34 B	Bituminous; run of mine	do	do	do	do	do	122	123	123		123	124		
Indiana:														
No. 1 B	Bituminous; screenings, through 1-inch screen.	No. 6	Mildred	Sullivan	Evansville and Terre Haute.	J. S. Burrows	125	125						125
No. 5 B	Bituminous; screenings, through 1¼-inch bar screen.	No. 5	Hymera	do	do	Uninspected	126	126						126

Samples of fuels received and tests made, by States—Continued.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Indiana—Cont.														
No. 6 B	Bituminous; screenings, through 1¼-inch bar screen.	No. 4	Hymera	Sullivan	Evansville and Terre Haute.	Uninspected	127	127						127
No. 12	Bituminous; run of mine	No. 5	Hartwell	Pike	Southern	W. J. Von Borries.	128	128	129	129	130	130	130	
No. 13	do	No. 6	Terre Haute	Vigo	Vandalia	J. W. Groves	131	131	132	132				
No. 14	do	No. 3	Seelyville	do	do	F. B. Tough	133	133	134	134				
No. 15	do	No. 4	Linton	Greene	Southern Indiana.	do	135	135	135	136				
No. 16	do	No. 5	do	do	Vandalia	J. W. Groves	136	137	137	137				
No. 17	do	do	Bicknell	Knox	do	do	138	138	139			139	139	
No. 18 A	Bituminous; washed slack, through ⅛-inch wire-mesh revolving screen.	do	Ayrshire	Pike	Southern	do	140	141				142		
No. 18 B	Bituminous; lump, over 1¾-inch round shaking screen.	do	do	do	do	do	140	141	141	142				
No. 19	Bituminous; screenings, through 1¼-inch stationary-bar screen	Brazil Block (top).	Diamond	Parke	Chicago and Eastern Illinois.	do	143	143	144					144
No. 20	do	Brazil Block (bottom).	Brazil	Clay	do	do	145	145			145			146
Indian Territory:														
No. 2 B	Bituminous; slack, through ⅝-inch shaking screen.	Hartshorne	Hartshorne		Rock Island	Uninspected	146	147	147		148			148
No. 2 C	Bituminous; lump, over 1-inch shaking screen.	do	do		do	J. W. Groves	146	147	147					149
No. 8	Bituminous	(?)	(?)		do	Uninspected	150	150	150		151			
No. 9	Semianthracite; run of mine	(?)	Panama		Kansas City Southern.	do	151	151	151					152
Kansas:														
No. 2 B	Bituminous; slack	Weir-Pittsburg.	Yale	Crawford	Missouri Pacific	do	153	153	153		154			155
No. 6	Bituminous; lump, over 1¼-inch bar screen.	do	Jewett	Linn	do	W. J. Von Borries.	156	156	156	157	157	158	158	
Kentucky:														
No. 2 B	Coke breeze		Earlington	Hopkins	Louisville and Nashville.		159				159			159
No. 8	Bituminous; run of mine	No. 1 B, or "Bell coal."	Sturgis	Union	Illinois Central	F. B. Tough	159	160	160			160	161	

No. 9 A	Bituminous: nut, through 1¼-inch and over ¾-inch screen.	No. 9	McHenry	Ohio	do	K. M. Way	162	162	....	....	163	163	163	....
No. 9 B	Bituminous; run of mine	do	do	do	do	do	162	162	163	....	....	....	....	....
Maryland No. 2	do	Pittsburg	Frostburg	Allegany	Baltimore and Ohio.	J. W. Groves	165	165	165	....	....	....	....	166
Missouri:														
No. 5	do	(?)	Higbee	Randolph	Chicago and Alton.	do	167	167	167	....	168	168	168	....
No. 6	Bituminous; lump, over 6-inch bar screen.	(?)	Huntsville	do	Wabash	do	169	169	170	....	....	....	....	....
No. 7 A	Bituminous; No. 1 nut	(?)	Novinger	Adair	Quincy, Omaha and Kansas City.	W. J. Von Borries	170	171	171	....	172	....	....	....
No. 7 B	Bituminus; No. 2 nut	(?)	do	do	do	do	170	171	171	....	172	....	....	....
No. 10	Bituminous; screenings, through ¾-inch shaking screen.	Bevier	Bevier	Macon	Chicago, Burlington and Quincy	K. M. Way	172	172	173	....	....	....	....	173
Montana:														
No. 2	Lignite	(?)	Fromberg	Carbon	Northern Pacific.	N. H. Darton	174	174	175	175	....	....	....	....
No. 3	do	(?)	Bridger	do	do	do	176	176	176	177	....	....	....	....
New Mexico:														
No. 3 A	Bituminous; run of mine	Main Raton, or Lower Laramie.	Van Houten	Colfax	Atchison, Topeka and Santa Fe.	J. S. Burrows	177	178	178	179	....	....	180	....
No. 3 B	Bituminous; lump, over ¾-inch screen.	do	do	do	do	do	177	178	178	....	....	179	....	....
No. 3 C	Bituminous; slack, through ¾-inch screen.	do	do	do	do	do	177	178	178	....	179	179	....	....
No. 4 A	Bituminous; run of mine	do	Brilliant	do	do	do	181	181	182	182	183	....	....	....
No. 4 B	Bituminous; slack, through 1¼-inch screen.	do	do	do	do	do	181	181	182	....	183	183	183	....
No. 5	Bituminous; run of mine	do	Blossburg	do	do	do	184	184	185	185	186	186	186	....
Ohio:														
No. 10	Bituminous; lump, over 1¼-inch bar screen.	No. 5	Mineral City	Tuscarawas	Baltimore and Ohio; Pennsylvania lines.	J. W. Groves	187	187	188	188	....	....	....	....
No. 11	do	No. 8	Flushing	Belmont	Baltimore and Ohio.	do	189	189	189	190	....	....	....	....
No. 12	Bituminous; run of mine	do	Bellaire	do	Baltimore and Ohio; Pennsylvania lines.	K. M. Way	190	191	191	191	192	193	....	....
Pennsylvania:														
No. 7	do	Pittsburg	Ligonier	Westmoreland	Ligonier Valley	do	193	194	194	....	....	....	....	....
No. 11	do	do	Charleroi	Washington	Pennsylvania	J. W. Groves	194	195	....	195	....	195	196	....
No. 12	do	do	Acheson	do	Baltimore and Ohio.	do	197	197	....	197	198	198	198	....
No. 13	do	Freeport	Creighton	Allegheny	Pennsylvania	do	200	200	....	200	....	....	....	....
No. 15	do	B, or Miller	Wehrum	Indiana	do	do	201	201	202	202	203	203	....	204
No. 16	do	D	Hastings	Cambria	do	K. M. Way	204	205	205	206	....	....	....	206
No. 17	do	Upper Freeport.	White	Indiana	do	A. K. Adams	207	207	208	208	209	209	....	....
No. 18	do	B, or Miller	Lloydell	Cambria	do	K. M. Way	210	2 0	211	....	....	....	....	211
No. 19	do	Pittsburg	Herminie	Westmoreland	do	A. K. Adams	213	214	214	....	....	215	....	215
No. 20	do	Lower Kittanning.	Seward	do	do	J. W. Groves	216	216	217	....	217	218	....	2 8

Samples of fuels received and tests made, by States—Continued.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Pennsylvania—Continued.														
No. 21	Bituminous; run of mine	Pittsburg	Connellsville	Fayette	Pennsylvania	A. K. Adams	219	219	....	....	....	220	220	....
No. 22	do	do	Huff	Westmoreland	do	J. W. Groves	221	221	221	222	....	....	....	222
Rhode Island No. 1.	Graphitic	(?)	Cranston	Providence		J. S. Burrows	223	223	224	....	....	263	....	204
Tennessee:														
No. 1	Bituminous; run of mine	Mingo	Fork Ridge	Claiborne	Louisville and Nashville.	W. J. Von Borries	224	225	225	226	226	226	227	228
No. 2	do	Log Mountain	Gatliff	Campbell	do	J. W. Grooves	228	229	229	230	....	230	230	....
No. 3	do	Regal Block	do	do	do	do	231	232	232	233	....	233	233	....
No. 4	do	Windrock, or Dean.	Oliver Springs.	Roane	do	do	234	235	235	236	....	236	237	237
No. 5	do	Brushy Mountain.	Petros	Morgan	Southern	do	238	239	239	240	240	240	241	....
No. 6	do	Lower Sewanee.	Waldensia	Cumberland	do	do	241	242	242	243	....	243	243	....
No. 7 A	Bituminous; screenings, over ¼- by 1-inch screen.	Wilder	Wilder	Fentress	do	do	244	245	245	246	....	....	....	....
No. 7 B	Bituminous; slack, through ¼- by 1-inch screen.	do	do	do	do	do	244	245	245	....	246	246	247	247
No. 8 A	Bituminous; special, run of mine.	First above Sewanee.	Clifty	White	Nashville, Chattanooga and St. Louis.	do	248	249	249	249	250	250	251	....
No. 8 B	Bituminous; screened, run of mine.	do	do	do	do	do	248	249	249	249	250	250	251	....
No. 9 A	Bituminous; lump, over ¾-inch screen.	Sewanee	Coalmont	Grundy	do	do	251	252	252	....	....	....	....	....
No. 9 B	Bituminous; raw slack	do	do	do	do	do	251	252	252	....	253	253	253	254
No. 9 C	Bituminous; washed slack	do	do	do	do	do	251	252	252	....	....	253	253	254
No. 10	Bituminous; slack	Battle Creek	Orme	Marion	do	W. J. Von Borries	255	255	255	....	256	256	256	256
No. 11	Bituminous; slack, through 1¼-inch screen.	(?)	Ozone	Cumberland	Tennessee Central.	Uninspected	257	257	....	....	257	257	258	....
Texas:														
No. 3	Lignite; lump, over ¾-inch screen.	(?)	Olsen	Milam	International and Great Northern.	W. J. Von Borries	258	259	....	259	....	....	....	....

No. 4	Lignite; run of mine	(?)	Hoyt	do	Missouri, Kansas and Texas.	do	260	260	260	261				261
Utah:														
No. 1	Bituminous; run of mine	(?)	Huntington Creek.	Carbon		Uninspected	262	262	224	262		263	263	263
No. 2	Bituminous; slack, through 1¼-inch screen.	Coalville, or Grass Creek.	Coalville	Summit	Union Pacific	J. W. Groves	264	265	265					265
Virginia:														
No. 5 A	Anthracite; pea	Big seam	Blacksburg	Montgomery	Norfolk and Western.	R. T. Carroll	267	267	267	268				
No. 5 B	Anthracite; slack	do	do	do	do	do	267	267	267					268
No. 6	Bituminous; run of mine	No. 4	Richlands	Tazewell	do	J. W. Groves	269	270	270	270	271	272		
Washington:														
No. 1 A	Subbituminous; pea	(?)	Renton	King	Seattle Electric	M. R. Campbell	272	272		273				
No. 1 B	Subbituminous; run of mine	(?)	do	do	do	do	272	272	273	273				
No. 2	Bituminous; lump	(?)	Roslyn	Kittitas	Northern Pacific	do	274	275	275	276		276	276	277
West Virginia:														
No. 11 B	Bone	Pocahontas No. 3.	Zenith	McDowell	Norfolk and Western.	J. W. Groves	278	278		278				
No. 16 A	Bituminous; ¾ inch	Pittsburg	Monongah	Marion	Baltimore and Ohio.	J. S. Burrows	279	279	279					
No. 22 A	Bituminous; screenings, through 1¼-inch screen.	(?)	Hernshaw	Kanawha	Chesapeake and Ohio.	J. W. Groves	279	280	280		281			
No. 22 B	Bituminous; run of mine	(?)	do	do	do	do	279	280	280					
No. 23 A	do	Cedar Grove	Monarch	do	Kanawha and Michigan.	do	281	281	282					
No. 23 B	Bituminous; slack, through 1½-inch screen.	do	do	do	do	do	281	281	282		282			
No. 24	Bone	Pocahontas No. 3.	Gary	McDowell	Norfolk and Western.	A. K. Adams	282	283		282				
No. 25	Bituminous; lump, over 1¼-inch screen.	Black band	Charleston (8 miles southeast).	Kanawha	Chesapeake and Ohio.	J. W. Groves	283	283		283		284		
Wyoming:														
No. 4	Bituminous; run of mine	(?)	Hanna	Carbon	Union Pacific	do	284	284	285	285				
No. 5	do	Rock Springs.	Rock Springs.	Sweetwater	do	do	286	286		286		287		
No. 6	Subbituminous; run of mine	(?)	Kemmerer	Uinta	do	do	287	287	288	288				289
Miscellaneous:														
Coke, "miscellaneous."	Mixed coke						289	290		289				
Coke, "mixed."	do						290	290	290					
Collinsville, Ill.	Bituminous, nut		Collinsville	Madison	Vandalia	Uninspected	290	291	291					
Washery refuse.	Dumpings from washing tests on bituminous coals.						291	292	292					
No. 5	Coke breeze						292	292						293
No. 9	do						293	293						294
No. 10	Slack coal						295	295			295			

Samples of fuels received and tests made, by States—Continued.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Pennsylvania—Continued.														
No. 21	Bituminous; run of mine	Pittsburg	Connellsville	Fayette	Pennsylvania	A. K. Adams	219	219	....	....	....	220	220	....
No. 22	do	do	Huff	Westmoreland	do	J. W. Groves	221	221	221	222	....	....	....	222
Rhode Island No. 1.	Graphitic	(?)	Cranston	Providence		J. S. Burrows	223	223	224	....	....	263	....	204
Tennessee:														
No. 1	Bituminous; run of mine	Mingo	Fork Ridge	Claiborne	Louisville and Nashville.	W. J. Von Borries.	224	225	225	226	226	226	227	228
No. 2	do	Log Mountain	Gatliff	Campbell	do	J. W. Grooves	228	229	229	230	....	230	230	....
No. 3	do	Regal Block	do	do	do	do	231	232	232	233	....	233	233	....
No. 4	do	Windrock, or Dean.	Oliver Springs.	Roane	do	do	234	235	235	236	....	236	237	237
No. 5	do	Brushy Mountain.	Petros	Morgan	Southern	do	238	239	239	240	240	240	241	....
No. 6	do	Lower Sewanee.	Waldensia	Cumberland	do	do	241	242	242	243	....	243	243	....
No. 7 A	Bituminous; screenings, over ¼- by 1-inch screen.	Wilder	Wilder	Fentress	do	do	244	245	245	246	....	....	....	....
No. 7 B	Bituminous; slack, through ¼- by 1-inch screen.	do	do	do	do	do	244	245	245	....	246	246	247	247
No. 8 A	Bituminous; special, run of mine.	First above Sewanee.	Clifty	White	Nashville, Chattanooga and St. Louis.	do	248	249	249	249	250	250	251	....
No. 8 B	Bituminous; screened, run of mine.	do	do	do	do	do	248	249	249	249	250	250	251	....
No. 9 A	Bituminous; lump, over ¾-inch screen.	Sewanee	Coalmont	Grundy	do	do	251	252	252	....	....	....	....	....
No. 9 B	Bituminous; raw slack	do	do	do	do	do	251	252	252	....	253	253	253	254
No. 9 C	Bituminous; washed slack	do	do	do	do	do	251	252	252	....	....	253	253	254
No. 10	Bituminous; slack	Battle Creek	Orme	Marion	do	W. J. Von Borries.	255	255	255	....	256	256	256	256
No. 11	Bituminous; slack, through 1¼-inch screen.	(?)	Ozone	Cumberland	Tennessee Central.	Uninspected	257	257	....	....	257	257	258	....
Texas:														
No. 3	Lignite; lump, over ¾-inch screen.	(?)	Olsen	Milam	International and Great Northern.	W. J. Von Borries.	258	259	....	259	....	....	....	....

No. 4	Lignite; run of mine	(?)	Hoyt	do	Missouri, Kansas and Texas.	do	260	260	260	261					261
Utah:															
No. 1	Bituminous; run of mine	(?)	Huntington Creek.	Carbon		Uninspected	262	262	224	262		263	263		263
No. 2	Bituminous; slack, through 1½-inch screen.	Coalville, or Grass Creek.	Coalville	Summit	Union Pacific	J. W. Groves	264	265	265						265
Virginia:															
No. 5 A	Anthracite; pea	Big seam	Blacksburg	Montgomery	Norfolk and Western.	R. T. Carroll	267	267	267	268					
No. 5 B	Anthracite; slack	do	do	do	do	do	267	267	267						268
No. 6	Bituminous; run of mine	No. 4	Richlands	Tazewell	do	J. W. Groves	269	270	270	270	271	272			
Washington:															
No. 1 A	Subbituminous; pea	(?)	Renton	King	Seattle Electric	M. R. Campbell	272	272		273					
No. 1 B	Subbituminous; run of mine	(?)	do	do	do	do	272	272	273	273					
No. 2	Bituminous; lump	(?)	Roslyn	Kittitas	Northern Pacific	do	274	275	275	276		276	276		277
West Virginia:															
No. 11 B	Bone	Pocahontas No. 3.	Zenith	McDowell	Norfolk and Western.	J. W. Groves	278	278		278					
No. 16 A	Bituminous; ¾ inch	Pittsburg	Monongah	Marion	Baltimore and Ohio.	J. S. Burrows	279	279	279						
No. 22 A	Bituminous; screenings, through 1½-inch screen.	(?)	Hernshaw	Kanawha	Chesapeake and Ohio.	J. W. Groves	279	280	280		281				
No. 22 B	Bituminous; run of mine	(?)	do	do	do	do	279	280	280						
No. 23 A	do	Cedar Grove	Monarch	do	Kanawha and Michigan.	do	281	281	282						
No. 23 B	Bituminous; slack, through 1½-inch screen.	do	do	do	do	do	281	281	282		282				
No. 24	Bone	Pocahontas No. 3.	Gary	McDowell	Norfolk and Western.	A. K. Adams	282	283		282					
No. 25	Bituminous; lump, over 1½-inch screen.	Black band	Charleston (8 miles southeast).	Kanawha	Chesapeake and Ohio.	J. W. Groves	283	283		283		284			
Wyoming:															
No. 4	Bituminous; run of mine	(?)	Hanna	Carbon	Union Pacific	do	284	284	285	285					
No. 5	do	Rock Springs.	Rock Springs	Sweetwater	do	do	286	286		286		287			
No. 6	Subbituminous; run of mine	(?)	Kemmerer	Uinta	do	do	287	287	288	288					289
Miscellaneous:															
Coke, "miscellaneous."	Mixed coke						289	290		289					
Coke, "mixed."	do						290	290	290						
Collinsville, Ill.	Bituminous, nut		Collinsville	Madison	Vandalia	Uninspected	290	291	291						
Washery refuse.	Dumpings from washing tests on bituminous coals.						291	292	292						
No. 5	Coke breeze						292	292							293
No. 9	do						293	293							294
No. 10	Slack coal						295	295			295				

WORK OF THE CHEMICAL LABORATORY.

By N. W. Lord.

INTRODUCTION.

The principal work of the chemical laboratory for the period covered by this report consisted in making routine analyses and calorimetric determinations of the various coals tested at the fuel-testing plant. In addition to the regular work on coals, over 100 samples of pig iron from the cupola tests on cokes were analyzed for silicon, sulphur, and manganese. Complete analyses were made of several slags, also from the cupola tests. A large number of mine samples, sent into the laboratory by inspectors in different parts of the country, were analyzed.

A few special lines of research, involving a certain amount of additional analytical work, were also carried on at the plant, to study the characteristics of coals and to devise improvements in the methods of analysis employed. A report of this work is published in a bulletin of the Survey.[a]

EQUIPMENT.

The routine and special work has been carried on in the laboratory that was fitted up in the foundry building of the plant, as described in the report of the 1905 work.[b] The following additional equipment has been installed: A thermoelectric pyrometer, a number of extra platinum crucibles, and an arithmometer to facilitate the reduction and the tabulation of the results. The addition of a number of new filing cases and other new office furniture greatly facilitated the proper keeping of laboratory records.

CHANGES IN ANALYTICAL METHODS.

There has been only one change of moment in the methods used in the laboratory; this was in the method of determination of the "volatile matter" in lignites. The old method of analysis was the same as that used in the analysis of coals, and was found to give,

[a] Lord, N. W., Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, January 1, 1905, to July 31, 1906: Bull. U. S. Geol. Survey No. 323, 1907.

[b] See Bull. U. S. Geol. Survey No. 290, p. 29, 1906.

when applied to lignites, results which were too high, owing to the excessive moisture present. It was modified by introducing a short preliminary heating at a low temperature before applying the full heat of the burner. This procedure was found to make practically no difference in the results obtained with bituminous coals, while it gave much more concordant and satisfactory results when applied to lignites. The experiments on this subject and the comparison of results by both methods are treated in detail in Bulletin No. 323.

PERSONNEL.

Prof. E. E. Somermeier was associate chemist during the period; F. M. Stanton, head chemist; G. A. Burrell, first assistant, and Karl M. Way, E. C. Waters, and J. W. Peters, assistants. In April Mr. Waters resigned and was succeeded by J. A. McCalip, who resigned in September, being succeeded by D. I. Brown. Mr. Way was transferred to the field section in August and was succeeded by G. O. Spitler. R. C. Willis was added to the force in December and J. H. Birdsong in January, 1907.

WORK OF THE LABORATORY.

During the period covered by this report, 2,100 samples of coal have been received in the laboratory, representing 21 States, 2 Territories, and 2 foreign fields.

The proximate analysis and the determination of sulphur was made on practically all these samples, and on a large number of them the ultimate analysis and the determination of calorific value were also made. These determinations, with such other analyses as were made of special materials employed in the tests, involved more than 12,000 separate determinations.

The reduction of the results from the air-dried samples to the basis of condition as received, the calculation of the ultimate analyses and of the calorific values of the samples used in the steaming tests and the gas-producer tests, and the figuring of these results to the dry-coal basis were also performed by the laboratory force, involving practically the entire time of one man as a computer.

The analytical results are presented in the detailed report of tests on each sample. (See table, pp. 14–19.)

The analyses of mine and car samples given in this report are figured to the sample as received. In reporting the analyses of the coals used in steaming tests and all briquets, the proximate analysis is figured to the basis of coal "as received," but the ultimate analysis is figured on the dry-coal basis.

STEAMING TESTS.

By L. P. Breckenridge.

EQUIPMENT.

The equipment of the steam-boiler section consisted of two Heine water-tube boilers,[a] similar in construction and setting. The principal proportions of the boiler settings are as follows:

Leading proportions of the boilers installed at the fuel-testing plant.

	Boiler No. 1.	Boiler No. 2.
Rated capacity of boiler ..... horsepower..	210	210
Water-heating surface ..... square feet..	2,031	2,031
Superheating surface	None.	None.
Grate area ..... square feet..	40.55	36.4
Air space through grate ..... per cent..	45	35
Available stack draft ..... inch of water..	.75	.75
Height of steel stacks ..... feet..	115	115
Area of steel stacks ..... square feet..	7.67	7.67
Number of 3½-inch tubes on each boiler	116	116
Usual steam pressure carried ..... pounds..	80	80

Each boiler is provided with its own stack and fed by its own injector.

Boiler No. 1 was equipped with a plain grate and boiler No. 2 with the McClave rocking grate, but all the tests during the latter half of the period (tests 402–519) were conducted with a plain grate. Unless otherwise stated in the detailed report of steaming tests the plain grate was used. The furnace was of the Heine standard tile-roof type; no change was at any time made in the design.

PERSONNEL.

The following men were members of the steam-boiler section during the period covered by this report: Walter T. Ray, Henry Kreisinger, Harry W. Weeks, Charles H. Green, Robert H. Kuss, William M. Park, Fred Pahmeyer, Lloyd R. Stowe, R. H. Post, Ralph Galt, George S. Pope, G. E. Ryder, Fred W. Bird, Perry Barker, Lyman S. Weeks, Carl J. Fletcher, Clarence E. Woodman, and Charles E. Augustine. During the period Messrs. Green, Kuss, Park, Pahmeyer, Post, and L. S. Weeks resigned, and Messrs. Galt, Pope, and Ryder were assigned to other sections of the fuel investigations.

[a] See Prof. Paper U. S. Geological Survey No. 48, p. 301, and Bulls. U. S. Geol. Survey Nos. 261, p. 74; 290, p. 33; and 325, p. 173.

COALS TESTED.

In the scope of this report are included the results of 214 steaming tests on 106 coals from 23 domestic States and Territories and from Argentina, as follows:

Steaming tests made, by States.

Coal.	Number of tests.
Alabama:	
No. 2 B	3
No. 3	2
No. 4	5
No. 5	2
No. 6	1
Argentina No. 1	3
Arkansas:	
No. 7 A	2
No. 8	3
No. 10	1
Florida No. 1	1
Georgia No. 1	1
Illinois:	
No. 7 E	1
No. 9 C	2
No. 12 B	1
No. 19 C	2
No. 19 D	2
No. 19 E	2
No. 20	3
No. 21	3
No. 22 A	3
No. 23 A	4
No. 24 B	3
Nos. 25 A and 25 B (mixed)	2
No. 26	2
No. 27	2
No. 28 A	1
No. 28 B	1
No. 28 C	2
No. 29 A	1
No. 29 B	3
No. 30	1
No. 31	2
No. 33	1
No. 34 B	1
Indiana:	
No. 12	3
No. 13	2
No. 14	2
No. 15	2
No. 16	2
No. 17	2
No. 18 B	2
Indiana—Continued.	
No. 19	1
Indian Territory:	
No. 2 B	3
No. 2 C	1
Nos. 2 B and 2 C (mixed)	1
No. 8	1
No. 9	2
Kansas:	
No. 2 B	3
No. 6	2
Kentucky:	
No. 8	2
No. 9 B	1
Maryland No. 2	3
Missouri:	
No. 5	2
No. 6	2
No. 7 A	2
No. 7 B	1
No. 10	1
Montana:	
No. 2	1
No. 3	1
New Mexico:	
No. 3 A	1
No. 3 B	2
No. 3 C	1
No. 4 A	2
No. 4 B	1
No. 5	1
Ohio:	
No. 10	1
No. 11	2
No. 12	1
Pennsylvania:	
No. 7	1
No. 15	3
No. 16	2
No. 17	2
No. 18	2
No. 19	2
No. 20	2
No. 22	1
Rhode Island No. 1	1
Tennessee:	
No. 1	5
No. 2	3
No. 3	2
No. 4	3
No. 5	3
No. 6	3
No. 7 A	3
No. 7 B	1
Nos. 8 A and 8 B (mixed)	3
No. 9 A	3
Nos. 9 B and 9 C (mixed)	1
No. 10	2
Texas No. 4	3
Utah:	
No. 1 with Rhode Island No. 1	2
No. 2 with Rhode Island No. 1	1
No. 2	3
Virginia:	
No. 5 A	2
No. 5 B	1
No. 6	1
Washington:	
No. 1 B	1
No. 2	4
West Virginia:	
No. 16 A	2
No. 22 A	3
No. 22 B	1
No. 23 A	2
No. 23 B	2
Wyoming:	
No. 4	1
No. 6	2
Miscellaneous:	
Mixed coke	1
Collinsville	7
Washery refuse	1
	214

The detailed results of the steaming tests may be found by referring to the index table on pages 14–19. The results of eleven additional tests, run for special purposes during the period, are not included in this report, but will appear later, with discussions, and those of seven tests made during the period on coals received in 1905 are also reserved for future publication.

Many interesting conclusions are obtainable from the "boiler tests" so far made, but a discussion of them will require so much space that it has been decided to present all such conclusions, together with a large amount of experimental work, in a separate publication entitled "A Study of Four Hundred Steaming Tests."[a]

[a] Bull. U. S. Geol. Survey No. 325, 1907.

Samples of fuels received and tests made, by States—Continued.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Indiana—Cont.														
No. 6 B	Bituminous; screenings, through 1¼-inch bar screen.	No. 4	Hymera	Sullivan	Evansville and Terre Haute.	Uninspected	127	127						127
No. 12	Bituminous; run of mine	No. 5	Hartwell	Pike	Southern	W. J. Von Borries.	128	128	129	129	130	130	130	
No. 13	do	No. 6	Terre Haute	Vigo	Vandalia	J. W. Groves	131	131	132	132				
No. 14	do	No. 3	Seelyville	do	do	F. B. Tough	133	133	134	134				
No. 15	do	No. 4	Linton	Greene	Southern Indiana	do	135	135	135	136				
No. 16	do	No. 5	do	do	Vandalia	J. W. Groves	136	137	137	137				
No. 17	do	do	Bicknell	Knox	do	do	138	138	139			139	139	
No. 18 A	Bituminous; washed slack, through ⅜-inch wire-mesh revolving screen.	do	Ayrshire	Pike	Southern	do	140	141				142		
No. 18 B	Bituminous; lump, over 1¾-inch round shaking screen.	do	do	do	do	do	140	141	141	142				
No. 19	Bituminous; screenings, through 1¼-inch stationary-bar screen	Brazil Block (top).	Diamond	Parke	Chicago and Eastern Illinois.	do	143	143	144					144
No. 20	do	Brazil Block (bottom).	Brazil	Clay	do	do	145	145			145			146
Indian Territory:														
No. 2 B	Bituminous; slack, through ⅜-inch shaking screen.	Hartshorne	Hartshorne		Rock Island	Uninspected	146	147	147		148			148
No. 2 C	Bituminous; lump, over 1-inch shaking screen.	do	do		do	J. W. Groves	146	147	147					149
No. 8	Bituminous	(?)	(?)		do	Uninspected	150	150	150		151			
No. 9	Semianthracite; run of mine	(?)	Panama		Kansas City Southern.	do	151	151	151					152
Kansas:														
No. 2 B	Bituminous; slack	Weir-Pittsburg.	Yale	Crawford	Missouri Pacific	do	153	153	153		154			155
No. 6	Bituminous; lump, over 1¼-inch bar screen.	do	Jewett	Linn	do	W. J. Von Borries.	156	156	156	157	157	158	158	
Kentucky:														
No. 2 B	Coke breeze		Earlington	Hopkins	Louisville and Nashville.		159				159			159
No. 8	Bituminous; run of mine	No. 1 B, or "Bell coal."	Sturgis	Union	Illinois Central	F. B. Tough	159	160	160			160	161	

No. 9 A	Bituminous: nut, through 1¼-inch and over ¾-inch screen.	No. 9	McHenry	Ohio	do	K. M. Way	162	162			163	163	163		
No. 9 B	Bituminous: run of mine	do	do	do	do	do	162	162	163						
Maryland No. 2	do	Pittsburg	Frostburg	Allegany	Baltimore and Ohio.	J. W. Groves	165	165	165						166
Missouri:															
No. 5	do	(?)	Higbee	Randolph	Chicago and Alton.	do	167	167	167		168	168	168		
No. 6	Bituminous; lump, over 6-inch bar screen.	(?)	Huntsville	do	Wabash	do	169	169	170						
No. 7 A	Bituminous; No. 1 nut	(?)	Novinger	Adair	Quincy, Omaha and Kansas City.	W. J. Von Borries	170	171	171		172				
No. 7 B	Bituminus; No. 2 nut	(?)	do	do	do	do	170	171	171		172				
No. 10	Bituminous; screenings, through ¾-inch shaking screen.	Bevier	Bevier	Macon	Chicago, Burlington and Quincy	K. M. Way	172	172	173						173
Montana:															
No. 2	Lignite	(?)	Fromberg	Carbon	Northern Pacific.	N. H. Darton	174	174	175	175					
No. 3	do	(?)	Bridger	do	do	do	176	176	176	177					
New Mexico:															
No. 3 A	Bituminous; run of mine	Main Raton, or Lower Laramie.	Van Houten	Colfax	Atchison, Topeka and Santa Fe.	J. S. Burrows	177	178	178	179			180		
No. 3 B	Bituminous; lump, over ¾-inch screen.	do	do	do	do	do	177	178	178			179			
No. 3 C	Bituminous; slack, through ¾-inch screen.	do	do	do	do	do	177	178	178		179	179			
No. 4 A	Bituminous; run of mine	do	Brilliant	do	do	do	181	181	182	182	183				
No. 4 B	Bituminous; slack, through 1¼-inch screen.	do	do	do	do	do	181	181	182		183	183	183		
No. 5	Bituminous; run of mine	do	Blossburg	do	do	do	184	184	185	185	186	186	186		
Ohio:															
No. 10	Bituminous; lump, over 1¼-inch bar screen.	No. 5	Mineral City	Tuscarawas	Baltimore and Ohio; Pennsylvania lines.	J. W. Groves	187	187	188	188					
No. 11	do	No. 8	Flushing	Belmont	Baltimore and Ohio.	do	189	189	189	190					
No. 12	Bituminous; run of mine	do	Bellaire	do	Baltimore and Ohio; Pennsylvania lines.	K. M. Way	190	191	191	191	192	193			
Pennsylvania:															
No. 7	do	Pittsburg	Ligonier	Westmoreland	Ligonier Valley	do	193	194	194						
No. 11	do	do	Charleroi	Washington	Pennsylvania	J. W. Groves	194	195		195		195	196		
No. 12	do	do	Acheson	do	Baltimore and Ohio.	do	197	197		197	198	198	198		
No. 13	do	Freeport	Creighton	Allegheny	Pennsylvania	do	200	200		200					
No. 15	do	B. or Miller	Wehrum	Indiana	do	do	201	201	202	202	203	203			204
No. 16	do	D	Hastings	Cambria	do	K. M. Way	204	205	205	206					206
No. 17	do	Upper Freeport.	White	Indiana	do	A. K. Adams	207	207	208	208	209	209			
No. 18	do	B. or Miller	Lloydell	Cambria	do	K. M. Way	210	210	211						211
No. 19	do	Pittsburg	Herminie	Westmoreland	do	A. K. Adams	213	214	214			215			215
No. 20	do	Lower Kittanning.	Seward	do	do	J. W. Groves	216	216	217		217	218			218

Samples of fuels received and tests made, by States—Continued.

Field number of sample.	Kind of fuel.	Name of bed.	Locality.	County.	Railroad.	Inspector.	Page of this report on which are discussed the— Field work.	Chemical analyses.	Steaming tests.	Producer-gas tests.	Washing tests.	Coking tests.	Cupola tests.	Briquetting tests.
Pennsylvania—Continued.														
No. 21	Bituminous; run of mine	Pittsburg	Connellsville	Fayette	Pennsylvania	A. K. Adams	219	219	....	....	....	220	220	....
No. 22	do	do	Huff	Westmoreland	do	J. W. Groves	221	221	221	222	....	....	....	222
Rhode Island No. 1.	Graphitic	(?)	Cranston	Providence		J. S. Burrows	223	223	224	....	....	263	....	204
Tennessee:														
No. 1	Bituminous; run of mine	Mingo	Fork Ridge	Claiborne	Louisville and Nashville.	W. J. Von Borries	224	225	225	226	226	226	227	228
No. 2	do	Log Mountain	Gatliff	Campbell	do	J. W. Grooves	228	229	229	230	....	230	230	....
No. 3	do	Regal Block	do	do	do	do	231	232	232	233	....	233	233	....
No. 4	do	Windrock, or Dean.	Oliver Springs.	Roane	do	do	234	235	235	236	....	236	237	237
No. 5	do	Brushy Mountain.	Petros	Morgan	Southern	do	238	239	239	240	240	240	241	....
No. 6	do	Lower Sewanee.	Waldensia	Cumberland	do	do	241	242	242	243	....	243	243	....
No. 7 A	Bituminous; screenings, over ¼- by 1-inch screen.	Wilder	Wilder	Fentress	do	do	244	245	245	246	....	....	....	....
No. 7 B	Bituminous; slack, through ¼- by 1-inch screen.	do	do	do	do	do	244	245	245	....	246	246	247	247
No. 8 A	Bituminous; special, run of mine.	First above Sewanee.	Clifty	White	Nashville, Chattanooga and St. Louis.	do	248	249	249	249	250	250	251	....
No. 8 B	Bituminous; screened, run of mine.	do	do	do	do	do	248	249	249	249	250	250	251	....
No. 9 A	Bituminous; lump, over ¾-inch screen.	Sewanee	Coalmont	Grundy	do	do	251	252	252	....	....	....	....	....
No. 9 B	Bituminous; raw slack	do	do	do	do	do	251	252	252	....	253	253	253	254
No. 9 C	Bituminous; washed slack	do	do	do	do	do	251	252	252	....	....	253	253	254
No. 10	Bituminous; slack	Battle Creek	Orme	Marion	do	W. J. Von Borries	255	255	255	....	256	256	256	256
No. 11	Bituminous; slack, through 1½-inch screen.	(?)	Ozone	Cumberland	Tennessee Central.	Uninspected	257	257	....	....	257	257	258	....
Texas:														
No. 3	Lignite; lump, over ¾-inch screen.	(?)	Olsen	Milam	International and Great Northern.	W. J. Von Borries.	258	259	....	259	....	....	....	....

No. 4	Lignite; run of mine	(?)	Hoyt	do	Missouri, Kansas and Texas.	do	260	260	260	261				261
Utah:														
No. 1	Bituminous; run of mine	(?)	Huntington Creek.	Carbon		Uninspected	262	262	224	262		263	263	263
No. 2	Bituminous; slack, through 1¼-inch screen.	Coalville, or Grass Creek.	Coalville	Summit	Union Pacific	J. W. Groves	264	265	265					265
Virginia:														
No. 5 A	Anthracite; pea	Big seam	Blacksburg	Montgomery	Norfolk and Western.	R. T. Carroll	267	267	267	268				
No. 5 B	Anthracite; slack	do	do	do	do	do	267	267	267					268
No. 6	Bituminous; run of mine	No. 4	Richlands	Tazewell	do	J. W. Groves	269	270	270	270	271	272		
Washington:														
No. 1 A	Subbituminous; pea	(?)	Renton	King	Seattle Electric	M. R. Campbell	272	272		273				
No. 1 B	Subbituminous; run of mine	(?)	do	do	do	do	272	272	273	273				
No. 2	Bituminous; lump	(?)	Roslyn	Kittitas	Northern Pacific	do	274	275	275	276		276	276	277
West Virginia:														
No. 11 B	Bone	Pocahontas No. 3.	Zenith	McDowell	Norfolk and Western.	J. W. Groves	278	278		278				
No. 16 A	Bituminous; ¾ inch	Pittsburg	Monongah	Marion	Baltimore and Ohio.	J. S. Burrows	279	279	279					
No. 22 A	Bituminous; screenings, through 1¼-inch screen.	(?)	Hernshaw	Kanawha	Chesapeake and Ohio.	J. W. Groves	279	280	280		281			
No. 22 B	Bituminous; run of mine	(?)	do	do	do	do	279	280	280					
No. 23 A	do	Cedar Grove	Monarch	do	Kanawha and Michigan.	do	281	281	282					
No. 23 B	Bituminous; slack, through 1¼-inch screen.	do	do	do	do	do	281	281	282		282			
No. 24	Bone	Pocahontas No. 3.	Gary	McDowell	Norfolk and Western.	A. K. Adams	282	283		282				
No. 25	Bituminous; lump, over 1¼-inch screen.	Black band	Charleston (8 miles southeast).	Kanawha	Chesapeake and Ohio.	J. W. Groves	283	283		283		284		
Wyoming:														
No. 4	Bituminous; run of mine	(?)	Hanna	Carbon	Union Pacific	do	284	284	285	285				
No. 5	do	Rock Springs	Rock Springs	Sweetwater	do	do	286	286		286		287		
No. 6	Subbituminous; run of mine	(?)	Kemmerer	Uinta	do	do	287	287	288	288				289
Miscellaneous:														
Coke, "miscellaneous."	Mixed coke						289	290		289				
Coke, "mixed."	do						290	290	290					
Collinsville, Ill.	Bituminous, nut		Collinsville	Madison	Vandalia	Uninspected	290	291	291					
Washery refuse.	Dumpings from washing tests on bituminous coals.						291	292	292					
No. 5	Coke breeze						292	292						293
No. 9	do						293	293						294
No. 10	Slack coal						295	295			295			

Summary of results of producer-gas tests January 1, 1906, to March 1, 1907.

	Bituminous coal.				Lignite.				Bone coal.				Peat.
	Number of tests.	Average.	Maximum.	Minimum.	Number of tests.	Average.	Maximum.	Minimum.	Number of tests.	Average.	Maximum.	Minimum.	
Calorific value per pound of fuel, as fired ..... B. t. u.	56	12,232	14,170	10,013	10	8,887	10,685	6,356	2	9,555	10,545	8,566	8,127
Calorific value per pound of fuel, dry ..... do	56	13,062	14,524	11,547	10	11,467	12,798	10,492	2	9,733	10,861	8,606	10,289
Calorific value per cubic foot of standard gas from fuel ..... do	56	151.0	171.6	122.5	10	154.8	181.5	125.3	2	125.1	144.0	106.3	175.2
Gas per pound of fuel, as fired ..... cubic feet	38	61.0	94.0	45.5	3	40.3	45.9	31.9	2	60.4	76.8	44.1	30.3
Gas per pound of fuel, dry ..... do	38	64.9	96.4	51.3	3	48.1	50.1	47.1	2	61.8	79.2	44.3	38.3
Fuel, per square foot of fuel-bed area per hour, as fired ..... pounds	42	7.35	10.50	4.67	5	11.18	13.25	8.46	2	7.77	9.82	5.72	15.2
Fuel, per square foot of fuel-bed area per hour, dry ..... do	42	6.84	9.30	4.56	5	8.72	9.30	7.74	2	7.66	9.77	5.55	12.0
Calorific value of gas per brake horsepower hour ..... B. t. u.	42	11,314	12,580	9,700	5	11,290	11,880	10,750	2	10,375	10,480	10,270	12,840
Equivalent fuel per electrical horsepower developed, as fired ..... pounds	41	1.57	2.24	0.99	5	2.37	2.75	1.74	2	[a] 1.91	2.16	1.68	3.03
Equivalent fuel per electrical horsepower developed, dry ..... do	41	1.46	1.99	0.97	5	1.85	2.06	1.59	2	[a] 1.89	2.14	1.63	2.39
Ratio of total fuel used under boiler per electrical horsepower to total fuel used in gas producer per electrical horsepower	29	2.84	3.66	2.43	4	2.64	2.90	2.24	.....	.....	.....	.....	2.30
Mixture of tar, water, and soot delivered by tar extractor per ton of fuel:													
After water separator was installed ..... pounds	15	308	624	92	2	224	338	110	.....	.....	.....	.....	157
Before water separator was installed ..... do	3	193	396	52	6	220	289	118	.....	.....	.....	.....	.....
Composition of fuel:													
Moisture ..... per cent	56	6.48	14.77	1.62	10	22.84	39.43	8.51	2	1.69	2.91	0.47	21.00
Volatile matter ..... do	56	32.21	42.46	9.70	10	31.77	37.18	25.54	2	10.32	11.81	8.83	51.72
Fixed carbon ..... do	56	50.23	69.01	38.81	10	35.11	45.69	24.37	2	52.08	57.19	46.96	22.11
Ash ..... do	56	11.08	20.57	3.70	10	10.28	15.39	2.74	2	35.91	43.74	28.08	5.17
Sulphur ..... do	56	2.30	5.14	0.28	10	0.57	0.88	0.47	2	0.41	0.54	0.27	0.45
Composition of gas produced (volumetric):													
Carbon dioxide (CO_2) ..... do	47	9.9	12.2	7.9	7	10.8	13.2	8.0	1	9.7	.....	.....	12.4
Oxygen (O_2) ..... do	47	0.0	0.1	0.0	7	0.2	0.7	0.0	1	0.0	.....	.....	0.0
Carbon monoxide (CO) ..... do	47	19.2	23.4	16.4	7	18.8	23.2	13.9	1	19.5	.....	.....	21.0
Hydrogen (H_2) ..... do	47	15.0	20.5	12.6	7	15.4	19.3	12.8	1	16.6	.....	.....	18.5
Methane (CH_4) ..... do	47	02.2	2.9	1.0	7	2.6	3.3	1.7	1	1.6	.....	.....	2.2
Nitrogen (N_2) ..... do	47	53.2	57.2	48.2	7	51.8	57.4	46.5	1	52.6	.....	.....	45.5
Ethylene (C_2H_4) ..... do	47	0.5	0.7	0.1	7	0.4	0.7	0.0	1	0.0	.....	.....	0.4

[a] Estimated. The actual average amount of bone coal consumed in the producer per electrical horsepower hour was 1.71 pounds as fired and 1.69 pounds of dry coal. It is estimated that the equivalent of this coal required to make the steam used in the producer was 0.2 pound per electrical horsepower hour.

WASHING TESTS.

By G. R. Delamater.

INTRODUCTION.

During the first six months of the period covered by this report the washing tests were conducted under the direction of John D. Wick, assisted by Edward Moore. J. H. Gould was in charge of the tests from July 16, 1906, to October 13, 1906, and G. R. Delamater was in charge from November 15, 1906, throughout the balance of the period.

EQUIPMENT AND OPERATION.

The Stewart jig used during 1905[a] was employed in making all tests until February 22, 1906, when the washer plant was almost entirely destroyed by fire, and with it a few samples of coal that were stored in the bins. The plant was immediately rebuilt, and similar equipment and methods were used for the tests made till November 15, 1906.

During December, 1906, a special jig was installed. This jig was of the center-plunger type; that is, the plunger was directly beneath the screen, and its upward stroke caused the pulsation. The plunger had no valves, but instead valves were arranged in the sides of the jig body to admit the water supply on the downstroke of the plunger. Cams and springs were so arranged that the plunger had a slow downward and a quick upward stroke. The screen of this jig was 4 by 5 feet in area and was made of strips of No. 10 wire running lengthwise of the screen frame and set one-sixteenth of an inch apart. The length of stroke was adjustable up to 4 inches. The depth of the coal bed was also adjustable.

Owing to the fact that the power for operating the washer plant was furnished by a 12 by 16 inch Frost steam engine, belted to a main shaft from which the jigs and other machinery were driven, it was impossible to change the speed of the jigs. Better results could have been obtained on some coals tested had it been possible to change the speed to suit the length of stroke used.

[a] Bull. U. S. Geol. Survey No. 290, 1906, p. 31.

As the only crusher available for this work was an 18 by 24 inch Cornish tooth-roll crusher, it was impossible to crush some coals as fine as was desirable. However, an adjustable-mesh bumping screen was installed in January, 1907, in such a manner that the coal was first passed over this screen and the tailings then passed on to the crusher, while the coal which went through the screen dropped into the bin over the jig. The product of the crusher was then elevated again to the screen, and this cycle of operation was repeated until all the coal passed through the screen.

In December, 1906, a "float and sink" testing equipment was installed. Before each washing test was made samples of the raw coal, quartered down to 2 kilograms each, were tested on four different specific-gravity solutions. In this manner it was possible to make a preliminary determination of the result of a separation under varying percentages of washed coal and refuse, and the coal was then washed with the jig regulated to discharge, as refuse, a percentage about equal to the percentage found advisable from the float and sink tests. After a washing test was made a sample of the refuse was taken and quartered down to four samples of 2 kilograms each, and these were also tested on the specific-gravity solutions. The test showing the highest percentage of float coal and having an analysis which agreed fairly with that of the washed coal was then used in determining the percentage of loss of good coal in the refuse. In this manner the efficiency of the test was shown.

EXPLANATION OF THE WASHING-TEST DATA.

The only parts of the washing-test tables requiring explanation are the "Per cent reduction" and "Amounts actually removed" as given in the note accompanying the tables. The per cent of reduction is obtained by comparing the percentages of impurities in the raw coal with those in the washed coal. It will be readily understood that if the ash alone be reduced by washing the fixed carbon and volatile matter will show a higher percentage in the washed coal than in the raw coal. However, in actual practice it is impossible to make so perfect a separation that there will be no portions of constituents other than the impurities removed in washing, and therefore the percentage of any one constituent in the washed coal is affected by the reduction of each of the other constituents. This is clearly indicated in test 192, on Alabama No. 6 (see p. 60), and in test 198, on Virginia No. 6 (see p. 271). By comparing the analyses of raw and washed coal in test 192 we find the same percentage of sulphur in the washed coal as in the raw coal, and in test 193 the sulphur in the washed coal is higher than it was in the raw coal. It will therefore be seen that a simple comparison of the analyses of raw and washed coal does not always show whether any of the sulphur in the raw coal was actually removed with the refuse in washing.

In order that this point might be determined, the following formulas were derived and used in making up this report. It will be noted by referring to the test data that in test 192 (p. 60) 10 per cent of the original sulphur in the raw coal was removed with the refuse in washing, and in test 198 (p. 271) 13 per cent of the original sulphur was removed.

Let X = the percentage of reduction of any constituent.

Y = the percentage of the constituent removed by washing.

M = the percentage that the amount of the constituent in the washed coal is of the amount in the raw coal.

a = the percentage that the washed coal is of the raw coal.

b = the percentage of the constituent in the washed coal.

c = the percentage of the constituent in the raw coal.

Then—

$$X = \frac{c-b}{c} \qquad M = ab \qquad Y = \frac{c-M}{c}$$

COALS TESTED.

During the period covered by this report[a] 61 washing tests were made on 57 coals from 14 domestic States and Territories and Argentina, as follows:

Washing tests made, by States.

Coal.	Number of tests.	Coal.	Number of tests.	Coal.	Number of tests.
Alabama:		Illinois—Continued.		New Mexico—Continued.	
No. 2 B	1	No. 29 A	2	No. 5	1
No. 3	1	No. 30	2	Ohio No. 12	1
No. 4	1	No. 34 A	1	Pennsylvania:	
No. 5	1	No. 34 B	1	No. 12	1
No. 6	1	Indiana:		No. 15	1
Argentina No. 1	2	No. 12	1	No. 17	1
Arkansas:		No. 20	1	No. 20	1
No. 1 B	1	Indian Territory:		Tennessee:	
No. 7 B	1	No. 2 B	1	No. 1	1
No. 8	1	No. 8	1	No. 5	1
No. 9	1	Kansas:		No. 7 B	1
Illinois:		No. 2 B	2	Nos. 8 A and 8 B mixed	1
No. 20	1	No. 6	1	No. 9 B	1
No. 21	1	Kentucky:		No. 10	1
No. 22 A	1	No. 2 B	1	No. 11	1
No. 22 B	1	No. 9 A	1	Virginia No. 6	1
No. 23 A	1	Missouri:		West Virginia:	
No. 23 B	1	No. 5	1	No. 22 A	1
No. 24 A	1	No. 7 A	1	No. 23 B	1
No. 24 B	1	No. 7 B	1	Miscellaneous No. 10	1
No. 25 A	1	New Mexico:			
No. 26	1	No. 3 C	1		
No. 27	1	No. 4 A	1		61
No. 28 C	1	No. 4 B	1		

The detailed results of the washing tests may be found on the pages referred to in the index table (pp. 14–19).

[a] Besides these tests, two tests not reported herein were made, as follows: Tests 155 and 154, Missouri Nos. 6 and 7, respectively (coal burned in the fire at the plant).

COKING TESTS.

By A. W. Belden.

INTRODUCTION.

The coking tests for the period covered by this report were made in the two beehive ovens that were employed in the 1905 tests, and the method of procedure was the same.[a]

The personnel of the section remained the same, the writer being assisted by W. E. Vickers, of Pocahontas, Va.

COALS TESTED.

In the scope of this report, covering the period from January 1, 1906, to February 20, 1907, are included results from 98 coking tests on 57 coals from 17 States and 1 Territory, as follows:

Coking tests made, by States.

Coal.	Number of tests.	Coal.	Number of tests.	Coal.	Number of tests.
Alabama:		Indiana:		Tennessee:	
No. 2 B	1	No. 12	3	No. 1	2
No. 3	2	No. 17	1	No. 2	1
No. 4	2	No. 18 A	2	No. 3	1
No. 5	1	Kansas No. 6	2	No. 4	2
No. 6	2	Kentucky:		No. 5	1
Arkansas:		No. 8	2	No. 6	1
No. 1 B	4	No. 9 A	1	No. 7 B	2
No. 7 B	2	Missouri No. 5	1	No. 8 B	1
No. 9	5	New Mexico:		No. 9	1
Georgia No. 1	1	No. 3 C	2	No. 10	1
Illinois:		No. 4 B	2	No. 11	1
No. 20	2	No. 5	2	Utah:	
No. 21	2	Nos. 3 C, 4 B, and 5 mixed	1	No. 1	1
No. 22 B	2	Ohio No. 12	1	No. 1 (with Rhode Island No. 1)	2
No. 23 A	1	Pennsylvania:		Virginia No. 6	2
No. 23 B	2	No. 11	1	Washington No. 2	1
No. 24 A	2	No. 12	2	West Virginia No. 25	1
No. 24 B	1	No. 15	2	Wyoming No. 5	1
No. 25 A	2	No. 17	2		
No. 26	1	No. 19	2		98
No. 27	1	No. 20	2		
No. 28 C	1	No. 21	5		
No. 29 A	2				
No. 34 B	1				

Of these 98 tests, 39 were made on raw coal, 51 on washed coal, 5 on washed coal with the addition of pitch, 1 on washed coal with the addition of asphalt, and 2 on raw coal with the addition of graphitic coal low in volatile matter.

[a] See Bull. U. S. Geol. Survey No. 290, 1906.

Of the 57 different coals, 4 produced no coke, viz, Illinois No. 21, Illinois No. 24 A, Indiana No. 18 A, and Wyoming No. 5.

Two efforts were made (tests 141 and 157) to improve coke from Utah No. 1, by mixing with this coal 33⅓ per cent and 25 per cent, respectively, of Rhode Island No. 1, a graphitic coal containing 4.92 per cent volatile matter, the idea being to reduce the volatile matter to approximate that contained in good coking coal. In the test 141 no coke was produced; test 157 gave 3,504 pounds of very inferior coke, and 3,208 pounds of breeze (p 263).

The results of the coking tests may be found in the detailed report of each sample presented on the following pages.

FUTURE WORK.

It has been decided to move this section of the plant to Denver, Colo., in order to take up the question of producing coke from western coals and to experiment further with the addition of volatile hydrocarbons to noncoking coals and to coals producing an inferior grade of coke. Tests will also be made with the mixing of coals, and different degrees of fineness of crushing. The scope of the work will be extended to include by-product coke.

CUPOLA TESTS ON COKE.

By Richard Moldenke.

EQUIPMENT.

Owing to the removal of one of the cupolas which served for the tests on foundry coke during the Louisiana Purchase Exposition, all the tests made since then were conducted in the 36-inch Whiting foundry cupola. The 36-inch shell was relined to 26 inches internal diameter. There were four horizontal tuyeres 11 inches above the sand bottom, and the total tuyere area was 96 square inches, giving a ratio with the cupola area of 1 to 5.96. By training the crew properly it was possible to run off two heats a day without interruption.

PERSONNEL.

The cupola tests were conducted by W. G. Ireland, under the direction of A. W. Belden, the coke expert of the Geological Survey, and with the advice of Dr. Richard Moldenke, in charge of the cupola tests of the fuel-testing plant.

METHOD OF TESTING.

The method of testing has been fully described in the report of the fuel-testing plant for 1904.[a] It was sometimes necessary to vary the proportion of scrap to pig iron, according to the supply toward the end of the tests, but the total amounts were kept correct as planned for the general series of tests.

After completing the tests on the available cokes in the regular way, so that the results might be comparable with the previous work of the section, a further series of tests was made on some of these cokes. In these tests the bed coke was not kept at a constant height above the tuyeres, but the carbon content was calculated from the analysis of the particular coke, and a sufficient amount taken to make up 175 pounds of carbon, regardless of the height above the tuyeres. The results, which show interesting features, are withheld for a publication

[a] Prof. Paper U. S. Geol. Survey No. 48, pt. 3, 1906, pp. 1367–1370.

dealing with coals received during 1905. Some cokes gave better melting ratios and melting rates per hour than with the ordinary test methods and others gave inferior results. The tests were made to show the advisability, on the part of the manufacturer as well as of the foundryman, of studying the conditions of cupola practice with a view to adopting those methods which give the best results.

COKES TESTED.

The results of 69[a] cupola tests on 33 different cokes made from fuels from 11 States and 1 Territory are included in this report. Many of these tests are on washed samples, and several of the tests were repeated in order to get more satisfactory results. The origin of the samples and the number of tests made are as follows:

Cupola tests made on coke, by States.

Coal.	Number of tests.	Coal.	Number of tests.	Coal.	Number of tests.
Alabama:		Missouri No. 5	1	Tennessee—Continued.	
No. 2 B	2	New Mexico:		No. 6	2
No. 3	3	No. 4 B	1	No. 7 B	2
No. 4	4	Nos. 3 B, 4 B, and 5 mixed	2	Nos. 8 A and 8 B mixed	2
Arkansas:		No. 5	1	Nos. 9 B and 9 C mixed	2
No. 1 B	2	Pennsylvania:		No. 10	2
No. 7 B	2	No. 11	2	No. 11	2
No. 9	2	No. 12	6	Utah No. 1	1
Illinois:		No. 21	1	Washington No. 2	2
No. 22 B	1	Tennessee:			
No. 29 A	3	No. 1	3		
Indiana:		No. 2	2		69
No. 12	1	No. 3	2		
No. 17	1	No. 4	3		
Kansas No. 6	1	No. 5	2		
Kentucky:					
No. 8	3				
No. 9 A	3				

The detailed results of the standard series of tests on these cokes may be found by referring to the index table (pp. 14–19).

[a] This number does not include the tests on fuels received during 1905, many of which were conducted during this period. These tests are reserved for future publication.

BRIQUETTING TESTS.

By C. T. Malcolmson.

INTRODUCTION.

During the latter part of 1905 tests were conducted [a] on briquets made in the briquetting machine built by William Johnson & Sons, Leeds, England, and hereinafter called the "English" machine. No attempt was made to obtain data on these tests other than superficial observations on combustion. The results were entirely satisfactory, and it was therefore decided to continue, during 1906, to make briquets from the surplus of samples of coal sent to the plant, in order to substantiate with practical tests the conclusions reached from laboratory experiments made during the previous year.

PERSONNEL.

On January 1, 1906, the writer was instructed to proceed with these investigations. W. J. Chapman was placed in charge of the operation of the machines, making the briquets used in the tests and assisting as observer in obtaining the accompanying data, and Robert Strasser, of Vienna, was placed in charge of the chemical laboratory of this section. To this staff were added G. E. Ryder, in charge of locomotive tests, assisted by Ralph Galt as gas chemist and computer and C. W. Vocke as observer; also C. L. Wright, in charge of physical tests.

EQUIPMENT.

The work of briquetting the samples already reported for other tests made during 1905 [b] was barely started when the briquetting plant and all stored briquets and fuels were entirely destroyed or ruined by fire. In rebuilding the plant, provision was made for the installation of an experimental briquetting machine of the plunger type, built in St. Louis after several years of experimentation and known herein as the "Renfrow" machine. The fundamental difference between it and the English machine is that the Renfrow machine

[a] Bull. U. S. Geol. Survey No. 290, 1906, pp. 40-52.
[b] Bull. U. S. Geol. Survey No. 290, 1906.

makes briquets at each end of the stroke of the plunger. By this design the briquets are kept under compression in the dies twice as long for the same output as they are in machines of the English type. The same length of time for compression being assumed, however, and other conditions being equal, the Renfrow machine has double the output of other plunger-type machines. The period of compression is determined by experience and fixes the speed of the machine. The longer the pressure remains on the warm charge the greater the cohesion and the better the briquet, but the smaller the output.

Twelve briquets are made on the Renfrow machine at each end of the stroke, or 24 in each revolution. At 12 revolutions per minute the output was 4 tons per hour, on an average, for all fuels. The machine was successfully operated at 16 revolutions per minute with a relatively increased capacity, but the lower speed was better adapted to the experimental work. The pressure obtainable under ordinary working conditions never exceeded 1,000 pounds per square inch, whereas a pressure of 2,000 to 2,500 pounds per square inch is considered necessary to make satisfactory briquets. For this reason it was found necessary to use a softer pitch and a greater percentage of binder than on the English machine, in order to make good briquets. The fault was somewhat obviated on the Renfrow machine by the jacketed heaters, which made it possible to control absolutely the moisture content. Advices have been received that the Renfrow Company has begun the construction of a new machine capable of producing higher pressure, and much stronger and heavier in every way. The briquets will be 3¼ inches in diameter and will weigh 12 ounces each.

The English machine was not seriously damaged by the fire, but in repairing it considerable care was taken to strengthen certain parts, to provide better lubrication and alignment, and to replace the tight and loose pulleys with friction clutches. The new plant was first operated in May, 1906, and as a result of previous experience it contained some improvements in the methods of crushing, mixing, and conveying the fuel, and of preparing the fuel and binder before briquetting. The new auxiliary equipment for the two machines was not materially different from that originally belonging to the English machine.[a]

The foundation of the Stedman disintegrator was raised to a level with the floor so as to be more accessible. A storage bin of 40 tons capacity, divided into four equal compartments, was built sufficiently high above the charging floor to allow coal to be drawn by gravity into the hopper scales placed on this floor. A pitch cracker was so placed beside the scales that pitch from it and coal from the scales could pass uniformly to a mixing conveyor directly under the charging floor and be discharged into the disintegrator on the floor below. By

[a] Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 1392; Bull. U. S. Geol. Survey No. 290, 1906, p. 40.

this arrangement small samples of coal and binder could be turned on the charging floor and fed by hand into the conveyor through a hole in the floor. A bucket elevator and a divided chute provided with a gate served to convey the fuel from the disintegrator either to the agglomerating cylinder of the English machine or to the storage bin built above and directly behind the Renfrow machine. This bin contained an agitator to prevent the fine fuel from packing. The fuel was carried from the bin to the hoppers of the Renfrow machine by belt conveyors, the amount delivered being regulated by gates in the bottom of the bin. Provision was made for the use of either liquid or hard pitch as a binder for briquets made on the Renfrow machine. During the hot weather considerable difficulty was experienced in conveying the finely divided and thoroughly mixed coal and pitch from the disintegrator to the Renfrow machine. This difficulty was obviated by introducing the melted hard pitch into the coal as it entered the hoppers of the machine, care being taken to maintain uniform temperature and rate of flow of the pitch.

The bronze bushings of the dies in the Renfrow machine were renewed toward the end of the period, and it was thought advisable to place heavier springs behind the plungers, as those in the machine when it was installed had been badly jammed and weakened by double charges. Similar renewals were made on the English machine, in which all of the partition walls of the bronze bushings were cracked, owing to improper alignment of the plungers and unequal loading of the dies.

The necessity of maintaining a comparatively large force of common laborers about the plant for careful handling of samples, both in the raw and briquetted form, justified the use of more labor in the actual briquetting operations than would be found in a commercial plant. The thorough cleaning of all conveyors, bins, and auxiliary apparatus before briquetting each sample was of as much importance for comparative results as the actual briquetting of the fuel; consequently no attempt was made to develop mechanical means for doing this work.

THE BRIQUETS.

DESCRIPTION.

The essential differences between finished briquets from the English and Renfrow machines are (1) the shape, (2) the size, and (3) the cohesion of the warm briquet.

The English briquet is rectangular, 4¼ by 6¾ inches, and averages 2¾ inches in thickness and 3½ pounds in weight. The Renfrow briquet is made in biscuit shape, being a short cylinder 3 inches in diameter, having rounded ends, the thickness between the ends ranging from 1½ to 3 inches according to the fuel. The average weight is 8 ounces.

The difference in cohesion of these two briquets as they come from the machine is due mainly to the method of treating the fuel before compressing it into briquets. In the English machine a charge is fed into the agglomerating cylinder, where it is heated by passing steam through the mass, superheated steam being used if the coal is high in moisture. The finished briquet consequently contains an excess of moisture, which retards hardening and necessitates careful handling until the briquets become cold. In the treatment of fuel for the Renfrow machine, uncombined moisture is reduced to as low a point as practicable. The mixing of the mass is accomplished uniformly and continuously in jacketed cylinders, using superheated steam. Toward the end of this process the moisture content is raised to the amount requisite to make good briquets by the admission of wet steam or water, according to the temperature of agglomerate desired at the dies. By this means the moisture in the briquet is kept constant and at a minimum. The briquets are sprayed with water on ejection from the dies, and on delivery from the machine are sufficiently hard to be handled by coke forks and loaded for shipment.

BINDERS USED.

In accordance with the practice well established in Europe and the results of the laboratory experiments of the previous year, no binder has been considered except two of the pitches derived from the distillation of the tar obtained as a by-product in the manufacture of illuminating gas. The large and increasing use in this country of illuminating gas made by carburetting water gas with oil suggested the use of the pitch thereby obtained, which is known in this report as water-gas pitch (abbreviated to w. g. p.). The other pitch used is that derived from the destructive distillation of coal, and is here called coal-tar pitch (abbreviated to c. t. p.). The pitch derived from by-product coke ovens was not considered, on account of the small number of these ovens in this country. In order to obtain data which would be comparative, all briquets in any one lot were made with the same binder. The binder was as nearly uniform as would be found practicable in commercial operations where the quality of the pitch could not be absolutely controlled.

QUALITY OF PITCH.

No effort was made to determine the best quality of binder for each coal, or for each machine, because of the small amounts of the samples available. On account of the relatively low pressure obtainable on the Renfrow machine, the binder the smallest percentage of which was required to make briquets with satisfactory physical properties proved to be pitch just hard enough to be broken easily in the pitch cracker, while pitch from which more of the heavy oils had

been distilled produced less smoke. The hardness of the binder was determined by a compromise between these two factors. From 6 to 8 per cent of binder was used.

The "flowing test" for determining the hardness of the pitch was made in the following manner: The bulb of the thermometer was covered with a thin layer of melted pitch, which was allowed to harden. The thermometer was passed through a cork fitted in the mouth of a test tube, which held the bottom of the thermometer bulb 2 inches from the bottom of the tube. The test tube was then held in a vertical position in a beaker of boiling water. As the pitch became soft it gradually dropped from the thermometer in the form of a thread, and the temperature recorded when this thread reached the bottom of the test tube was called the "flowing point."

A fractional distillation of the pitch was made as another check on its quality. From this distillation the oils coming off under 572° F., between 572° and 680° F., and between 680° and 743° F. were recorded. The most reliable test that was found for determining the binding property of a pitch has already been described.[a] Pitch that at the temperature of the mouth could be bitten nearly through before breaking proved the most satisfactory binder for most coals briquetted.

The results of the tests on binders are given in the following table:

Tests and analyses of pitch binders.

Laboratory No.	Calorific value (B.t.u.).	Flowing point (°F.).	Oils by distillation (per cent).				Extraction analysis: Pitch extracted (sample as received) by CS_2 (per cent).
			Up to 572° F.	572° to 680° F.	680° to 743° F.	Total up to 743° F.	
2735	.....	186.8	Data lost in fire				58.56
2729	.....	255.0	.....do				61.20
2748	.....	144.0	.....do				89.20
2933	15,937	176.0	.....do				64.20
3258	16,373	179.6	3.66	12.30	15.23	31.19	80.27
3296	16,427	171.5	3.08	11.57	11.82	26.47	82.43
3410	16,478	175.1	.85	15.21	9.11	25.17	79.98
3486	16,407	186.8	1.75	6.00	17.00	24.70	85.57
3623	16,027	165.2	.85	11.15	10.15	25.15	69.26
3624	16,193	172.4	1.25	10.35	9.40	20.00	99.60
3692	16,103	158.0	1.89	10.90	1.03	22.82	69.71
3885	16,870	140.0	1.43	14.83	18.18	34.44	95.20
3962	16,196	159.8	3.00	12.75	10.75	26.50	77.79
4120	17,060	154.4	.75	11.25	17.25	29.25	97.70
4318	16,744	165.2	1.00	11.10	13.50	25.60	90.42
4319	16,139	158.0	2.75	10.35	9.90	23.00	66.25
4543	16,969	143.6	1.62	17.31	20.12	39.05	99.66
4625	16,576	156.2	1.61	9.56	14.30	25.47	90.56
4683	16,637	161.6	1.28	11.64	16.06	28.98	89.31
4806	16,864	143.6	1.09	9.44	15.23	25.76	96.90
4825	17,156	114.8	.46	1.05	4.25	5.76	100.00
4879	16,805	125.6	1.33	16.53	15.15	33.01	94.50

[a] Prof. Paper U. S. Geol. Survey No. 48, pt. 3, 1906, p. 1396.

PERCENTAGE OF BINDER.

In handling a given sample of coal various percentages of binder were used in briquetting lots of 600 pounds. The remainder of the coal was briquetted with the minimum percentage of binder found necessary to make a satisfactory briquet. In all cases the fuel and binder were both weighed separately, and the percentages of binder given are taken from these figures. The extraction analyses by carbon bisulphide, the results of which are given in the above table, were made from carefully selected samples of coals, pitches, and briquets, and the percentage of binder in the finished product was calculated from these determinations.

SAMPLING AND DRYING.

A majority of the coals sent in for briquetting tests only were slack coals and were unloaded on the ground. Unless these samples had been subjected to heavy rains they were taken direct to the briquet bins. Washed samples, very wet slack, and coals high in moisture were passed through the direct-heat rotating drier furnished by the C. S. Snow & Bartlett Company. In some cases, where the moisture content was very low, so that it was necessary to add considerable water to the coal, the water was added before grinding, samples for moisture being taken during the course of the day's run. Ordinarily, however, the coals and the binder were sampled as they were fed into the disintegrator. The steaming-test analyses of briquets were used where possible and are given in this report. When no steaming tests were made, the samples for analyses were taken as the briquets left the machine. All briquets shipped from the plant for test were sampled as loaded and not as taken from the machine.

TESTS ON BRIQUETS.

COMBUSTION TESTS.

The only method available for determining the relative heating values of briquets consisted in burning them under boilers, the conditions being uniform with those for the steaming tests on coals. These tests were made by the boiler section in every case where there was a sufficient number of briquets, and are reported under "Steaming tests" in this bulletin. When coal was not available to make enough briquets on each machine, with the same percentage of binder, for a complete steaming test on both the English and Renfrow briquets, the test was divided into five-hour runs on each machine.

Several small lots of briquets containing various percentages of binder were burned under the boiler to note the behavior of the bri-

quets in the fire and the effect on quantity of smoke, but the main test was on briquets of a uniform percentage of binder. In many tests it was necessary to break up the English briquets in order to obtain capacity on the boiler, although every effort was made to burn them unbroken for comparative results.

Besides these tests on briquets at the plant, two series of tests were run—one using the briquets in locomotive boilers, and the other in boilers for house heating. In the detailed reports given in this volume tests from which the briquets were used in locomotives are indicated by a star (*) attached to the test number, and those from which the briquets were used in house boilers by a dagger (†). In many tests the product was divided, part being used for a house test and part for a locomotive test. The reports on these special tests are reserved for publication in a subsequent bulletin.

DROP TESTS.

An effort was made to obtain reliable data on the crushing strength of the various briquets. After repeated trials on selected briquets from several runs, the record was abandoned, as the results from briquets made of the same coal and under similar conditions did not check. Briquets taken at random from the same lot differed widely. The following method of testing the strength of the briquets, called the "drop test," was chosen as an approximation of the handling to which they would be subjected in commercial use. A box, 24 inches square and 12 inches deep, was constructed with a bottom consisting of two trapdoors hinged at the sides and so closed as to be easily tripped open. This box was supported 6½ feet above a cast-iron plate, which was placed at the bottom of a second box 12 inches deep. Fifty pounds of briquets, placed in the upper box, were suddenly dropped upon the cast-iron plate. The mass was then screened on a 1-inch mesh wire screen, and all the pieces held were again dropped from the box; and so on until the dropping had been performed five times. The percentage of the weight of the pieces held at the last screening to the original weight of the briquets was called "per cent held by 1-inch screen," and the remainder was called "per cent through 1-inch screen."

TUMBLER TESTS.

The tumbler tests were chosen to obtain a fair record of the cohesion of the briquets, especially when subjected to abrasive action. The method used follows closely the one adopted by the French navy and used as a standard in France. The apparatus consisted of a tumbler manufactured by the S. Obermayer Company. A number of whole briquets weighing as near 50 pounds as possible

were placed in the tumbler and rotated for two minutes at a uniform speed of 28 r. p. m., after which the contents of the tumbler were screened through a 1-inch mesh screen and the finest again screened through a 10-mesh sieve. The pieces held by both screens were weighed and the data in the tables determined by these weights.

WEATHERING TESTS.

Small piles of all briquets made were labeled and placed in a yard exposed to the weather. Although all the briquets have not had uniform weather conditions, the length of the exposure is a fair basis for comparison. As no ideal briquet is available as a standard for comparison, it is difficult to give in a concise statement the actual condition of these briquets. The following is the key to the designation of condition given under "Weathering test:"

Condition A: Briquets practically in same condition as when put out. Surfaces show no signs of erosion or pitting. Briquets hard, with sharp edges, and fracture same as that of new briquets.

Condition B: Shape of briquets unchanged. Surfaces of those on top of pile have lost luster, with evidences of pitting; corners and edges worn off by erosion. All briquets firm, with fracture practically the same as that of new briquets.

Condition C: Top briquets appear similar to those in condition B, and show signs of further disintegration, having lost original sharp fracture. Erosion more evident on all briquets on outside of the pile. Inside briquets still firm, retaining original characteristics.

Condition D: Top briquets so badly disintegrated that they crumble to pieces on handling. Briquets in center of pile show signs of disintegration; luster of surfaces gone; edges soft, and break easily in the hand. Fracture not so sharp as when newly made, but briquets firm, and handled without breaking.

Condition E: Entire pile disintegrated. In many cases the only briquets retaining their original shape are those protected from the weather. Briquets can not be handled safely, but crush easily in the hand.

ABSORPTION TESTS.

The object of the absorption tests was to determine (1) the rate of absorption of water by the briquets each day; (2) the time required for the absorption to become practically complete; and (3) the time at which the absorption actually ceases or the briquet disintegrates. The apparatus consisted of a hydrostatic balance with containing tank and four galvanized-iron pans 24 by 36 by 6 inches. The total number of samples were tested in two sets—briquetting tests 138 to 198 and 199 to 250.

Four Renfrow briquets or one English briquet were taken as a sample from each representative lot of briquets tested. These briquets had been stored under cover directly after being made, so they may be safely considered as air-dried samples. So far as possible briquets with perfect surfaces were used.

The method used in testing was as follows:

(*a*) The sample was weighed in air to the nearest gram, on the upper part of the hydrostatic balance.

(*b*) The sample was then weighed in water by being submerged on the lower shelf of the balance, the hour and minute of this immersion being noted.

(*c*) The sample was removed from the balance, placed in pans, and covered with one-half inch of water.

(*d*) Each succeeding day at the same time as the first immersion the operation noted in *b* was repeated.

(*e*) The gain in weight was noted each day by subtracting the observation for that day from the weight noted in *b*.

(*f*) This gain in weight was calculated to per cent of the original weight of the dry briquet, and so recorded each day.

The hydrostatic balance was brought to perfect adjustment twice a day to correct for variation in density of water due to variations in its temperature, which was recorded three times daily.

DENSITY.

The apparent specific gravity, being the weight in air divided by the loss of weight in water, was calculated from readings *a* and *b* of the absorption tests.

SPECIAL TESTS.

Water-gas machine test.—The object of this test was (1) to determine if the briquets could be used as fuel for the production of water gas; (2) to compare the results obtained with those from retort coke; (3) to observe the behavior of the briquets in the apparatus.

The briquets made in test 164† (see p. 75) were shipped to the Mullanphy street station of the Laclede Gas Company, of St. Louis, Mo., and tested in an 8½-foot water-gas machine of the Lowe type. This machine has a rated capacity of 1,000,000 cubic feet in twenty-four hours. This test was made under the direction of W. A. Baehr, chief engineer of the company, and the observations given below were made by Mr. Wright.

Data from water-gas machine test.

Length of blast	minutes	5
Length of run	do	6
Total number of cycles		42
Total number of runs made		213
Total briquets used	pounds	85,100
Total gas recorded by meter in 48 hours	cubic feet	1,959,000
Correction for relief holder	do	56,100
Total gas made in 48 hours	do	1,902,900
Average temperature of gas metered	° F.	73
Total gas made in 48 hours corrected to 60° F.	cubic feet	1,854,000
Total oil used in 48 hours	gallons	7,710
Average pressure of air during blast	inches of water	22.5
Average steam pressure during runs	pounds	29.2
Briquets per 1,000 feet of gas as metered (corrected to 60° F.)	do	45.9
5-hour coke per 1,000 feet of gas as metered (corrected to 60° F.)	do	31.5
Oil per 1,000 feet gas as metered (corrected to 60° F.)	gallons	4.16
Average luminosity of gas made	candlepower	19.4
Average amount of gas made, with briquets	candle feet	4.65
Average amount of gas made, with 5-hour coke	do	5.60
Average heat value of gas made, with briquets	B. t. u.	624
Average heat value of gas made, with 5-hour coke	do	643
Average yield of gas as metered per run, with briquets	cubic feet	8,940
Average yield of gas as metered per run, with 5-hour coke	do	8,450
Average amount of oil per run	gallons	36.2

Cupola test.—The briquets made in test 247 (see p. 293) were sent to the Madison plant of the American Car and Foundry Company, of St. Louis, Mo., and were tested in a cupola under the direction of Mr. Ireland, of the coking section. The object of this test was to determine if the coke breeze when briquetted could be made to replace or be used in connection with coke in foundry practice. It was hoped that, by the addition of lime to the pitch as a binder, the briquets would be able to support the weight above until they became thoroughly coked through, the lime being available also as a flux.

Coke was used during the first charges and 150 pounds of briquets were used on each of the last five charges, although 100 pounds of fuel is the regular practice at the foundry. The briquets were considerably broken up during the charging of the iron, and finally, as they got down well into the cupola, they broke down entirely, letting the iron down below the melting zone. After dropping the bottom, about 1,500 pounds of unmelted iron was found in the cupola.

COALS TESTED.

In this report are included 134[a] briquetting tests on 53 coals from 16 domestic States and 1 Territory and one sample from Argentina, as follows:

Briquetting tests made, by States, etc.

Coal.	Number of tests.	Coal.	Number of tests.	Coal.	Number of tests.
Alabama:		Indiana—Continued.		Tennessee—Continued.	
No. 2 B	1	No. 19	1	No. 4 (with Miscellaneous No. 5)	2
No. 4	1	No. 20	1	No. 7 B	1
Argentina No. 1	1	Indian Territory:		Nos. 9 B and 9 C mixed	1
Arkansas:		No. 2 B	12	No. 10	1
No. 7 B	1	No. 2 C	4	Texas No. 4	1
No. 13	3	No. 9	1	Utah:	
Illinois:		Kansas No. 2 B	7	No. 1 (with Rhode Island No. 1)	1
No. 7 E	1	Maryland No. 2	4	No. 2	1
No. 9 C	4	Missouri No. 10	5	No. 2 (with Rhode Island No. 1)	1
No. 12 B	3	Pennsylvania:		Virginia No. 5 B	2
No. 20 (with Kentucky No. 2 B)	2	No. 15	1	Washington No. 2	1
No. 21	1	No. 15 (with Rhode Island No. 1)	1	Wyoming No. 6	1
No. 23 B	1	No. 16	3	Miscellaneous:	
No. 28 A	6	No. 18	9	No. 5	1
No. 28 B	5	No. 18 (with Miscellaneous No. 9)	4	No. 9	2
No. 29 A	2	No. 18 (with Rhode Island No. 1)	1		
No. 29 B	1	No. 19	3		
No. 30	3	No. 20	7		
No. 31	4	No. 22	3		
No. 33	4	Tennessee:			
Indiana:		No. 1	1		
No. 1 B	1	No. 4	1		
No. 5 B	2				
No. 6 B	2				
					134

The detailed results of the briquetting tests may be found by referring to the index table (pp. 14–19).

[a] This number does not include 14 tests conducted on coals received during 1905, which are withheld for future publication.

RESULTS OF TESTS, BY STATES.

The following are the detailed results of tests made on the various samples of coals received from January 1, 1906, to June 30, 1907, arranged alphabetically according to States, and showing in definite order (see index table, p. 14), under the head of each fuel, all the tests made on the different samples of that fuel.

ALABAMA.

ALABAMA NO. 2.[a]

Bituminous coal from Carbon Hill, Walker County, on the Frisco System, was designated Alabama No. 2 B. The coal as worked at a depth of 30 feet at this place averages 4 feet 6 inches in thickness.

One sample of run-of-mine coal was shipped under the supervision of J. S. Burrows to the testing plant, and was used in making steaming tests 382, 383, and 410 (on briquets); washing test 163; coking test 142 (washed coal); cupola tests 107 and 131; and briquetting test 131.

Two mine samples were taken for chemical analysis. Sample 3011 was taken 3,500 feet northeast of slope, where the coal measured 4 feet 5 inches in thickness. Sample 3012 was taken 3,500 feet north of slope, where the coal measured 4 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Alabama No. 2 B.

	Mine samples.		Car sample.	Steaming tests.[b]		
				382.	383.	410.
Laboratory No.	3011	3012	[c] 3211			
Air-drying loss	2.70	2.40	1.70			
Proximate:						
Moisture	4.71	4.51	3.95	3.80	3.95	3.43
Volatile matter	31.80	31.81	30.70	32.09	30.70	32.74
Fixed carbon	53.32	54.76	50.76	50.47	50.76	51.34
Ash	10.17	8.92	14.59	13.64	14.59	12.49
Sulphur	1.33	1.48	1.12	1.19	1.12	1.24
Ultimate:						
Hydrogen			4.57	4.35	4.30	4.77
Carbon			66.21	69.71	68.94	72.17
Nitrogen			1.49	1.57	1.55	1.58
Oxygen			12.02	8.95	8.85	7.27
Ash				14.18	15.19	12.93
Sulphur				1.24	1.17	1.28
Calorific value (as received):						
Determined, calories	6,998		6,547			
Determined, B. t. u.	12,596		11,785			
Calculated from ultimate analysis, calories			6,433			
Calculated from ultimate analysis, B. t. u.			11,579			

[a] For tests of coal from this mine made during 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 32, 80, 88, 122; Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 38, 197, 337, 1017, 1328.
[b] Proximate analysis of coal as fired; ultimate analysis of dry coal figured from car sample.
[c] Sample taken from steaming test 383.

STEAMING TESTS.

Alabama No. 2 B (run of mine).

	Test 382.	Test 383.	Test 410.
Size as used:			
Over 1 inch ... per cent	65.4	48.3	See p. 49.
½ inch to 1 inch ... do	19.4	26.7	
¼ inch to ½ inch ... do	6.5	12.1	
Under ¼ inch ... do	8.7	12.9	
Duration of test ... hours	10.0	10.03	9.98
Heating value of fuel ... B. t. u. per pound dry fuel	12,411	12,269	12,856
Force of draft:			
Under stack damper ... inch water	0.69	0.64	0.61
Above fire ... do	.14	.12	.15
Furnace temperature ... °F	2,280	2,020	2,215
Dry fuel used per square foot of grate surface per hour ... pounds	23.53	17.26	18.13
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.87	2.83	3.26
Percentage of rated horsepower of boiler developed	108.6	79.2	91.4
Water apparently evaporated per pound of fuel as fired ... pounds	6.68	6.64	7.5
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	7.93	7.88	8.69
Per pound of dry fuel ... do	8.24	8.20	9.00
Per pound of combustible ... do	9.80	9.92	10.24
Efficiency of boiler, including grate ... per cent	64.12	64.54	67.60
Fuel as fired:			
Per indicated horsepower hour ... pounds	3.57	3.59	3.25
Per electrical horsepower hour ... do	4.40	4.43	4.02
Dry fuel:			
Per indicated horsepower hour ... do	3.43	3.45	3.14
Per electrical horsepower hour ... do	4.24	4.26	.88

Remarks.—Test 410 on briquets from test 131; Renfrow briquets during the first half and English briquets during the last half of the test. No difference was noted in the action of the two kinds of briquets while burning, both burning with a long flame without smoke, coking and holding together well. The Renfrow briquets as fired were badly broken up. No clinker; ash of gray color and medium weight.

WASHING AND COKING TESTS.

Alabama No. 2 B (run of mine).

Washing test 163.—Size as used, crushed to 2 inches; jig used, Stewart. Raw coal, 15,860 pounds; washed, 13,700 pounds; refuse, 2,160 pounds.

Coking test 142.—Size as used, washed, finely crushed. Duration of test, 51 hours. Coal charged, 10,530 pounds. Coke produced, 6,197 pounds; 58.85 per cent. Breeze produced, 684 pounds; 6.50 per cent. Total yield, 65.35 pounds. Poor coke, soft and dense.

Analyses.

	Washing test 163.		Coking test 142.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	3.95	6.29	6.26	3.04
Volatile matter	30.70	.....	31.99	1.06
Fixed carbon	50.76	.....	52.66	82.15
Ash	14.59	9.39	9.09	13.75
Sulphur	1.12	1.22	1.36	1.16

Cupola tests of coke made from Alabama No. 2 B coal (washed).

CHARGE.

Cupola test No.	Coke.				Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Phosphorus.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
		Per ct.			*Per ct.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
107	142	0.0700	1.88	7	99.9	Coke	200	58	58	57	57	430
						Pig iron	600	413	413	412	412	2,250
						Scrap	200	138	138	137	137	750
131	142	.0700	1.88	7	99.9	Coke	200	58	58	57	57	430
						Pig iron	600	413	413	412	412	2,250
						Scrap	200	138	138	137	137	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
107	1.59 p. m.	7	5	2,257	322	2,579	31	4,991	6.56	6.9	214	37
131	10.42 a. m.	7	7	1,852	365	2,217	29	4,587	5.80	12.33	413	48

LADLE RECORD.

Ladle No.	Test 107.		Test 131.		Ladle No.	Test 107.		Test 131.	
	Pounds.	Time (p. m.).	Pounds.	Time (a. m.).		Pounds.	Time (p. m.).	Pounds.	Time (a. m.).
1	69	2.11	33	10.51	15	75	2.26	90	11.11
2	69	2.11½	79	10.53	16	79	2.26½	62	11.11½
3	89	2.16	77	10.56	17	81	2.27	102	11.12
4	98	2.16½	30	10.57	18	89	2.28	94	11.13
5	82	2.19	74	10.58½	19	69	2.29	60	11.13½
6	101	2.19½	73	10.59	20	85	2.30	86	11.14
7	70	2.20	68	11.03	21	102	2.30½	20	11.14½
8	81	2.22	72	11.04	22	79	2.31	86	11.15
9	83	2.22½	76	11.04½	23	69	2.31½	53	11.15½
10	89	2.23	46	11.05	24	83	2.33	86	11.16
11	87	2.23½	71	11.07	25	103	2.33½	82	11.17
12	95	2.24	60	11.07½	26	52	2.34	131	11.18
13	82	2.25	94	11.08	27	97	2.35	.....	.....
14	99	2.25½	47	11.08½					

Remarks.—Test 107: Iron very hot and fluid.

BRIQUETTING TEST.

Alabama No. 2 B (run of mine).

Test 131.—Size as used: Over ¼ inch, 2.8 per cent; $\frac{1}{10}$ inch to ¼ inch, 11.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 21.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 23.4 per cent, through $\frac{1}{40}$ inch, 41 per cent. Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40); weight of fuel briquetted, 14,000 pounds. B. t. u. per pound of coal as received, 11,939; per pound of briquets as fired, 12,115; per pound of binder, 16,478. For analyses of briquets see page 47 (steaming test 410).

English briquets made at 175° F., average weight 3.31 pounds, with 5 and 6 per cent binder, proved to be good briquets; fracture clean; edges and surfaces firmer with 6 per cent than with 5 per cent binder. In the drop test with 5 per cent binder the

1-inch screen held 91.5 per cent and passed 8.5 per cent. In the weathering test all were exposed 197 days; condition, B.

Renfrow briquets made at 149° F., average weight 0.47 pound, with 6 per cent pitch, showed evidences of shortage in binder; surfaces crumbled and fracture not clean. Seven per cent binder made hard, firm surfaces; broke without crumbling, and surfaces and edges were firm. In the weathering test the 6 per cent binder briquets were exposed 201 days and those with 7 per cent 200 days; condition of both, B.

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 131.
Laboratory No.	3410	3211	.....
Air-drying loss ... per cent	.....	1.70	0.80
Extracted by CS_2:			
Air-dried ... do	.....	1.37	4.79
As received ... do	79.98	1.35	4.75
Pitch in briquets, as received ... do	.....	.....	4.32

ALABAMA NO. 3.

Bituminous coal from Garnsey, Bibb County, on the Louisville and Nashville Railroad, was designated Alabama No. 3. The coal as worked at a depth of 700 feet at this place averages 5 feet 6 inches in thickness.

Run-of-mine coal shipped under the supervision of John W. Groves was used in making steaming tests 390 and 394; washing test 161; coking tests 138 (raw) and 139 (washed); and cupola tests 101, 108, and 132.

Two mine samples were taken for chemical analysis. Sample 3018 was taken 2,700 feet south of the slope, where the coal measured 5 feet in thickness. Sample 3019 was taken 2,500 feet southwest of the slope, where the coal measured 5 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Alabama No. 3.

	Mine samples.		Car sample.	Steaming tests.[a]	
				390.	394.
Laboratory No.	3018	3019	3255	.....	.....
Air-drying loss	1.60	1.90	1.20	.....	.....
Proximate:					
Moisture	3.03	3.25	2.72	2.93	2.88
Volatile matter	30.94	30.43	29.46	28.03	29.58
Fixed carbon	55.31	54.16	53.46	48.25	49.12
Ash	10.72	12.16	14.36	20.79	18.42
Sulphur	.49	.53	.55	.55	.58
Ultimate:					
Hydrogen	.....	.....	4.55	4.03	4.15
Carbon	.....	.....	69.99	66.28	68.34
Nitrogen	.....	.....	1.14	1.08	1.11
Oxygen	.....	.....	9.41	6.62	6.83
Ash	.....	.....	.....	21.42	18.97
Sulphur	.....	.....	.....	.57	.60
Calorific value (as received):					
Determined ... calories	7,241	.....	6,923	.....	.....
Determined ... B. t. u.	13,034	.....	12,461	.....	.....
Calculated from ultimate analysis ... calories	.....	.....	6,829	.....	.....
Calculated from ultimate analysis ... B. t. u.	.....	.....	12,292	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Alabama No. 3 (run of mine).

		Test 390.	Test 394.
Size as used:			
Over 1 inch	per cent	19.9	13.7
½ inch to 1 inch	do	18.6	19.5
¼ inch to ½ inch	do	19.4	19.9
Under ¼ inch	do	42.1	46.9
Duration of test	hours	10.0	10.0
Heating value of coal	B. t. u. per pound dry coal	11,806	12,175
Force of draft:			
Under stack damper	inch water	0.55	0.60
Above fire	do	.18	.21
Furnace temperature	°F	2,040	2,160
Dry coal used per square foot of grate surface per hour	pounds	20.69	21.04
Equivalent water evaporated per square foot of water-heating surface per hour, pounds		3.31	3.38
Percentage of rated horsepower of boiler developed		92.7	94.8
Water apparently evaporated per pound of coal as fired	pounds	6.69	6.70
Water evaporated from and at 212°F:			
Per pound of coal as fired	do	7.77	7.82
Per pound of dry coal	do	8.00	8.05
Per pound of combustible	do	10.49	10.21
Efficiency of boiler, including grate	per cent	65.44	63.85
Coal as fired:			
Per indicated horsepower hour	pounds	3.64	3.62
Per electrical horsepower hour	do	4.49	4.47
Dry coal:			
Per indicated horsepower hour	do	3.54	3.51
Per electrical horsepower	do	4.36	4.34

WASHING AND COKING TESTS.

Alabama No. 3 (run of mine).

Washing test 161.—Size as used, crushed to 2 inches. Jig used, Stewart. Raw coal, 18,000 pounds; washed, 16,500 pounds; refuse, 1,500 pounds.

Coking tests.

		Test 138 (raw).	Test 139 (washed).
Size as used		f. c.	f. c.
Duration of test	hours	54	44
Coal charged	pounds	12,180	11,660
Coke produced	do	7,802	7,072
	per cent	64.06	60.65
Breeze produced	pounds	489	258
	per cent	4.01	2.21
Total yield	do	68.07	62.86

Remarks.—Test 138: Good, hard, heavy coke with exception of ¾-inch black butts, which should be easily removed. Ash should be very much lowered by washing. Test 139: Good, strong, hard, heavy coke; ash reduced, and much better coke than from raw charge; black butts removed.

Analyses.

	Washing test 161.		Coking test 138.		Coking test 139.	
	Raw coal (mine sample).	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	3.03	5.82	2.77	2.03	6.36	0.99
Volatile matter	30.94	.....	28.99	1.80	30.54	1.06
Fixed carbon	55.31	.....	53.14	74.89	53.10	83.51
Ash	10.71	10.01	15.10	21.28	10.00	14.44
Sulphur	.49	.58	.62	.60	.62	.58

Cupola tests of coke made from Alabama No.

CHARGE.

Cupola test No.	Coke.				Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Phosphorus.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
		Per ct.			*Per ct.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
132	138 (raw)	0.0057	1.91	7	97.22	Coke	210	55	55	55	55	430
						Pig iron	630	405	405	405	405	2,250
						Scrap	210	135	135	135	135	750
101	139(w.)	.0008	1.99	7	99.9	Coke	210	55	55	55	55	430
						Pig iron	630	405	405	405	405	2,250
						Scrap	210	135	135	135	135	750
108	139(w.)	.0008	1.99	7	94.44	Coke	210	55	55	55	55	430
						Pig iron	630	405	405	405	405	2,250
						Scrap	210	135	135	135	135	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
132	2.49 p. m.	7	12	740	214	954	26	2,201	3.21	4.46	1,911	132
101	11.17 a. m.	7	10	1,695	305	2,000	35	3,429	5.63	6.43	807	75
108	3.39 p. m.	7	5	1,822	213	2,035	33	3,700	6.15	6.36	774	99

LADLE RECORD.

Ladle No.	Test 132.		Test 101.		Test 108.		Ladle No.	Test 132.		Test 101.		Test 108.	
	Lbs.	Time (p.m.).	Lbs.	Time (a.m.).	Lbs.	Time (p.m.).		Lbs.	Time (p.m.).	Lbs.	Time (a.m.).	Lbs.	Time (p.m.).
1	92	3.10	77	11.32	103	3.55	12	64	3.27	74	11.50	79	4.07
2	100	3.10½	91	11.36	119	3.55½	13			85	11.53	101	4.07½
3	61	3.11	97	11.36½	51	3.56	14			86	11.53½	102	4.08
4	77	3.13	72	11.43	69	4.00	15			67	11.54	58	4.08½
5	77	3.13½	72	11.43½	116	4.00½	16			78	11.56	61	4.12
6	70	3.16	70	11.44	102	4.01	17			95	11.56½	85	4.12½
7	34	3.16½	62	11.47	110	4.01½	18			71	11.57	95	4.13
8	65	3.18	76	11.47½	86	4.03½	19			73	11.59	81	4.16
9	34	3.19	73	11.48	107	4.04	20			97	11.59½	100	4.17
10	64	3.23	91	11.49	91	4.04½	21			65	12.00		
11	2	3.23½	74	11.49½	106	4.05	22			49	12.02		

Remarks.—Test 101: Iron hot. Test 108: Iron hot; slag filled up tuyeres after twentieth ladle and bottom had to be dropped.

ALABAMA NO. 4.

Bituminous coal from Cane Creek, 3 miles north of Belle Ellen, Bibb County, on the Louisville and Nashville Railroad, was designated Alabama No. 4. The coal as worked at a depth of 150 feet at this place averages 2 feet 11 inches in thickness.

The sample consisted of run-of-mine coal, inspected by John W. Groves, and was used in making steaming tests 375, 376, 377, 378, and 413 (on briquets); producer-gas test 109; washing test 159;

coking tests 131 (raw) and 136 (washed); cupola tests 103, 109, 124 and 133; and briquetting test 123.

Two mine samples were taken for chemical analysis. Sample 3034 was taken 900 feet northeast of the slope, where the coal measured 2 feet 10 inches in thickness. Sample 3035 was taken 1,500 feet northeast of the slope, where the coal measured 2 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Alabama No. 4.

	Mine samples.		Car sample.	Steaming tests.[a]				
				375.	376.	377.	378.	413.
Laboratory No.	3034	3035	3103					
Air-drying loss	2.60	2.40	5.50					
Proximate:								
Moisture	3.67	3.60	6.43	4.04	4.84	5.69	5.27	2.46
Volatile matter	33.55	34.08	28.56	30.27	28.17	26.94	28.72	32.27
Fixed carbon	59.64	59.86	52.09	55.26	52.70	49.48	52.78	56.55
Ash	3.14	2.46	12.92	10.48	14.29	17.89	13.23	8.72
Sulphur	1.22	1.50	1.08	1.29	1.22	1.05		1.18
Ultimate:								
Hydrogen			5.23	4.98	4.75	4.54	4.83	4.72
Carbon			69.07	76.16	72.67	69.36	73.90	76.96
Nitrogen			1.18	1.30	1.24	1.19	1.27	1.32
Oxygen			10.52	5.30	5.04	4.83	5.13	6.85
Ash				10.92	15.02	18.97	13.97	8.94
Sulphur				1.34	1.28	1.11	.90	1.21
Calorific value (as received):								
Determined, calories	7,998		6,886					
Determined, B. t. u.	14,396		12,395					
Calculated from ultimate analysis, calories			6,952					
Calculated from ultimate analysis, B. t. u.			12,514					

STEAMING TESTS.

Alabama No. 4 (run of mine).

	Test 375.	Test 376.	Test 377.	Test 378.	Test 413.
Size as used:					
Over 1 inch ... per cent	17.1	18.1	7.1	17.1	See p. 56.
½ inch to 1 inch ... do	20.2	18.0	12.4	19.5	
¼ inch to ½ inch ... do	22.1	17.3	16.8	25.2	
Under ¼ inch ... do	40.6	46.6	63.7	38.2	
Duration of test ... hours	10.17	9.77	10.00	8.03	9.07
Heating value of fuel ... B. t. u. per pound dry fuel	13,671	13,041	12,447	13,244	13,932
Force of draft:					
Under stack damper ... inch water	0.64	0.55	0.63	0.60	0.66
Above fire ... do	.20	.19	.22	.18	.10
Furnace temperature ... °F	2,461	(b)			2,430
Dry fuel used per square foot of grate surface per hour ... pounds	20.94	17.39	18.45	15.91	21.11
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.81	2.97	3.10	2.76	3.90
Percentage of rated horsepower of boiler developed	106.9	83.2	87.0	77.4	109.5
Water apparently evaporated per pound of fuel as fired ... pounds	7.37	6.88	6.73	7.04	7.75
Water evaporated from and at 212° F:					
Per pound of fuel as fired ... do	8.75	8.14	7.95	8.24	9.02
Per pound of dry fuel ... do	9.12	8.55	8.43	8.69	9.25
Per pound of combustible ... do	10.55	10.46	10.81	10.46	10.29
Efficiency of boiler, including grate ... per cent	64.42	63.31	65.40	63.36	64.12
Fuel as fired:					
Per indicated horsepower hour ... pounds	3.23	3.47	3.56	3.43	3.14
Per electrical horsepower hour ... do	3.99	4.29	4.39	4.24	3.87
Dry fuel:					
Per indicated horsepower hour ... do	3.10	3.31	3.35	3.25	3.06
Per electrical horsepower hour ... do	3.83	4.08	4.14	4.02	3.77

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] One-half of observations too low to be read with Wanner pyrometer.

[illegible] flame, coked [illegible] briquets were [illegible] y all [illegible] y; [illegible] t, and brittle [illegible] of [illegible] did not stick to the grate. Small [illegible]

PRODUCER-GAS TEST.

Alabama No. 4 (run of mine).

Test 109.— [illegible] of [illegible] a[illegible] lectrical horsepower, 195.0; average B. t. u. [illegible] 10[illegible] ired, 5,850 pounds.

	As fired.	Dry.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.33	1.29	1.12
Developed at switch board	1.25	1.21	1.06
Per brake horsepower:			
Commercially available	1.13	1.09	.95
Developed at engine	1.06	1.03	.90
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.45	1.40	1.22
Developed at switch board	1.36	1.32	1.15
Per brake horsepower:			
Commercially available	1.23	1.19	1.04
Developed at engine	1.16	1.12	.97

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.05	Carbon dioxide (CO_2)	10.1
Volatile matter	29.53	Carbon monoxide (CO)	17.0
Fixed carbon	54.78	Hydrogen (H_2)	14.5
Ash	12.64	Methane (CH_4)	1.9
Sulphur	1.15	Nitrogen (N_2)	56.1
		Ethylene (C_2H_4)	.4

WASHING AND COKING TESTS.

Alabama No. 4 (run of mine)

Washing test 159.—Size as used, crushed to 2 inches; jig used, Stewart. Raw coal, 17,000 pounds; washed, 14,470 pounds; refuse, 2,530 pounds.

Coking tests.

		Test 131 (raw).	Test 136 (washed).
Size as used		f. c.	f. c.
Duration of test	hours	47	49
Coal charged	pounds	12,000	12,000
Coke produced	do	7,706	6,809
	per cent	64.22	56.74
Breeze produced	pounds	281	239
	per cent	2.34	1.99
Total yield	do	66.56	58.73

Remarks.—Test 131: Good, strong coke, light-gray and silvery color; ash and sulphur high; might be improved by washing. (Compare test 136.) Test 136: Good, strong coke; light-gray and silvery color; breakage, good uniform size; ash and sulphur reduced very materially by washing.

Analyses.

	Washing test 159.		Coking test 131.		Coking test 136.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	6.43	6.82	4.17	0.29	7.28	0.35
Volatile matter	28.56	.....	30.37	.84	30.46	.42
Fixed carbon	52.09	.....	54.50	83.21	58.38	92.99
Ash	12.92	3.81	10.96	15.66	3.88	6.24
Sulphur	1.08	1.03	1.18	1.08	1.00	.87

Cupola tests of coke made from Alabama No. 4 coal.

CHARGE.

Cupola test No.	Coke.				Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Phosphorus.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
		Per ct.			*Per ct.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
103	131	0.0126	1.95	7	98.61	Coke	200	58	58	57	57	430
						Pig iron	600	413	413	412	412	2,250
						Scrap	200	138	138	137	137	750
124	131	.0126	1.95	7	80.55	Coke	220	53	53	52	52	430
						Pig iron	660	398	398	397	397	2,250
						Scrap	220	133	133	132	132	750
109	136(w.)	.008	1.95	7	99.9	Coke	190	60	60	60	60	430
						Pig iron	570	420	420	420	420	2,250
						Scrap	190	140	140	140	140	750
133	136(w.)	.008	1.95	7	98.61	Coke	200	58	58	57	57	430
						Pig iron	600	413	413	412	412	2,250
						Scrap	200	138	138	137	137	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
103	8.19 a. m.	7	11	1,451	217	1,668	33	3,033	5.49	4.90	1,185	126
124	10.04 a. m.	7	10	1,368	542	1,910	27	4,244	5.76	10.66	770	99
109	10.30 a. m.	7	7	2,328	153	2,481	27	5,513	6.93	6.16	334	72
133	10.53 a. m.	7	8	1,952	178	2,130	32	4,260	6.96	5.76	697	124

LADLE RECORD.

Ladle No.	Test 103.		Test 124.		Test 109.		Test 133.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).
1	66	8.35	91	10.19	54	10.41	51	11.07
2	95	8.38	34	10.19½	112	10.45	84	11.10
3	75	8.41	90	10.26	125	10.45½	94	11.11
4	36	8.42	76	10.26½	102	10.46	69	11.13
5	96	8.43	83	10.27	112	10.47	82	11.15
6	61	8.45	69	10.30	110	10.47½	105	11.15½
7	101	8.45½	72	10.31	69	10.48	80	11.16
8	70	8.51	92	10.32	108	10.51½	72	11.18½
9	88	8.51½	57	10.33	114	10.52	116	11.19
10	99	8.52	66	10.33½	92	10.52½	92	11.19½
11	94	8.56	90	10.34	113	10.53	83	11.20
12	97	8.56½	64	10.34½	104	10.55	107	11.22
13	90	8.57	53	10.35	105	10.55½	102	11.22½
14	104	8.59	80	10.37	108	10.56	80	11.23
15	96	8.59½	53	10.37½	100	10.56½	106	11.23½
16	88	9.00	99	10.38	97	10.57	68	11.24
17	95	9.03	66	10.38½	118	10.57½	101	11.26
18	.....	.....	72	10.40	110	10.58	104	11.27
19	.....	.....	61	10.41	80	10.59	77	11.27½
20	.....	.....	.....	.....	110	11.02	84	11.28
21	.....	.....	.....	.....	96	11.03	52	11.29
22	.....	.....	.....	.....	80	11.03½	103	11.32
23	.....	.....	.....	.....	109	11.04	40	11.33

Remarks.—Test 103: Temperature of iron, medium. uggish. Test 109: Iron very hot and fluid.

BRIQUETTING TEST.

Alabama No. 4 (run of mine).

Test 123.—Size as used: Over $\frac{1}{4}$ inch, 1.2 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 4.5 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 14 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 23.5 per cent; through $\frac{1}{40}$ inch, 56.8 per cent. Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40). Weight of fuel briquetted, 15,200 pounds. B. t. u. per pound of coal as received, 12,395; per pound of briquets as fired, 13,590; per pound of binder, 16,478. For analyses of briquets see page 53 (steaming test 413).

English briquets made at 179.6° F., 3.37 pounds average weight, with 5.5 per cent binder, had edges that crumbled slightly, but surfaces were firm; fracture slightly crumbly. With 6, 6.5, and 7 per cent binder the outer surfaces were smooth and hard, fracture clean, and broken surfaces rough but very firm. In the drop test with 6 per cent binder the 1-inch screen held 83.3 per cent and passed 16.7 per cent. In the weathering test briquets of all binders were exposed 214 days; condition B.

Renfrow briquets made at 149° F., 0.43 pound average weight, with 6 and 6.5 per cent binder, were crumbly and broke easily; broken surfaces crumbly. With 7 and 7.5 per cent binder tough briquets resulted, with hard and smooth outer surfaces; broke with clean fracture. In the weathering test all binders were exposed 214 days; condition for the 7.5 per cent binder, B, for the others, C.

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 123.
Laboratory No	3410	3103	.....
Air-drying loss ... per cent	.....	5.50	0.90
Extracted by CS_2:			
Air-dried ... do	.....	.46	4.90
As received ... do	78.98	.43	4.86
Pitch in briquets, as received ... do	.....	.....	5.57

ALABAMA NO. 5.

Bituminous coal from the Black Creek bed at Lehigh, Blount County, on the Louisville and Nashville Railroad, was designated Alabama No. 5. The coal, as worked from the outcrop of this place, averages 2 feet 8 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in steaming tests 478 and 480, washing test 195, and coking test 171.

Two mine samples were taken for chemical analysis. Sample 4090 was taken 2,000 feet south of the opening, where the coal measured 3 feet in thickness. Sample 4091 was taken 2,100 feet south of the opening, where the coal measured 2 feet 4½ inches in thickness.

CHEMICAL ANALYSES.

Alabama No. 5.

	Mine samples.		Car sample.	Steaming tests.[a]	
				478.	480.
Laboratory No	4090	4091	4252	.....	.....
Air-drying loss	3.60	1.90	4.40	.....	.....
Proximate:					
Moisture	4.72	2.93	5.59	5.51	5.70
Volatile matter	28.69	29.06	25.05	24.15	23.85
Fixed carbon	62.45	65.28	53.28	50.44	52.74
Ash	4.14	2.73	16.08	19.90	17.71
Sulphur	.83	.65	1.40	1.90	1.47
Ultimate:					
Hydrogen	.....	.....	4.70	4.09	4.22
Carbon	.....	.....	66.58	66.58	68.94
Nitrogen	.....	.....	1.27	1.27	1.31
Oxygen	.....	.....	9.92	4.99	5.19
Ash	.....	.....	.....	21.06	18.18
Sulphur	.....	.....	.....	2.01	1.56
Calorific value determined (as received). calories	.....	81.63	66.16	.....	.....
Calorific value determined (as received). B. t. u.	.....	146.93	119.06	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Alabama No. 5 (run of mine).

		Test 478.	Test 480.
Size as used:			
Over 1 inch	per cent	4.8	4.1
½ inch to 1 inch	do	13.8	15.3
¼ inch to ½ inch	do	19.5	22.7
Under ¼ inch	do	61.9	57.9
Average diameter	inch	0.38	0.39
Duration of test	hours	9.93	9.57
Heating value of coal	B. t. u. per pound of dry coal	11,932	12,335
Force of draft:			
Under stack damper	inch water	0.89	0.86
Above fire	do	.19	.09
In ash pit (forced draft)	do	.....	.25
Furnace temperature, °F		2,561	.....
Dry coal used per square foot of grate surface per hour	pounds	19.01	22.86
Equivalent water evaporated per square foot of water-heating surface per hour	do	2.94	3.73
Percentage of rated horsepower of boiler developed		82.6	104.6
Water apparently evaporated per pound of coal as fired	pounds	6.08	6.40
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	7.33	7.70
Per pound of dry coal	do	7.76	8.17
Per pound of combustible	do	10.34	10.65
Efficiency of boiler, including grate	per cent	62.80	63.96
Coal as fired:			
Per indicated horsepower hour	pounds	3.85	3.67
Per electrical horsepower hour	do	4.76	4.53
Dry coal:			
Per indicated horsepower hour	do	3.64	3.46
Per electrical horsepower hour	do	4.50	4.27

WASHING TEST.

Alabama No. 5 (run of mine.)

Test 195 (preliminary float and sink tests on raw coal[a]).

Float and sink test No.	Size used.	Specific gravity of solution used.	Float (per cent).	Sink (per cent).	Float coal analysis.			
					Ash.		Sulphur.	
					Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
1	¾ inch	1.35	81	19	2.18	86	0.81	42
2	do	1.40	85	15	2.63	84	.98	30
3	do	1.45	87	13	2.66	84	1.05	25
4	do	1.52	87	13	3.19	80	1.13	19

[a] Not enough coal for other tests.

COKING TEST.

Alabama No. 5 (run of mine).

Test. 171.—Size as used, raw, finely crushed. Duration of test, 42 hours; coal charged, 12,110 pounds; coke produced, 7,950 pounds, 65.65 per cent; breeze produced, 390 pounds, 3.22 per cent; total yield, 68.87 per cent. Good coke, light gray and silvery. Ash high; washing would improve, reducing both ash and sulphur.

Analyses.

	Coal.	Coke.
Moisture	3.98	0.59
Volatile matter	26.55	.89
Fixed carbon	56.92	81.10
Ash	12.55	17.42
Sulphur	1.44	1.16

ALABAMA NO. 6.

Bituminous coal from the Pratt bed at Dolomite, Jefferson County, was designated Alabama No. 6. This coal, as worked from the outcrop at this place, averages 4 feet 8 inches in thickness.

This sample consisted of run-of-mine coal shipped under the supervison of K. M. Way, and was used in steaming test 484, producer-gas test 155, washing test 192, and coking tests 172 and 174 (washed).

Two mine samples were taken for chemical analysis. Sample 4292 was taken 2 miles southeast of the opening, where the coal measured 4 feet 8¼ inches in thickness. Sample 4293 was taken 2 miles east of the opening, where the coal measured 4 feet 8¼ inches in thickness.

CHEMICAL ANALYSES.

Alabama No. 6.

	Mine samples.		Car samples.		Steaming test 484.[a]
Laboratory No.	4292	4293	4338	4353	.....
Air-drying loss	2.30	2.20	2.40	2.80	.....
Proximate:					
Moisture	3.23	2.81	3.23	3.56	2.86
Volatile matter	26.97	26.52	26.16	26.24	25.80
Fixed carbon	65.97	67.16	63.90	63.25	63.98
Ash	3.83	3.51	6.71	6.95	7.36
Sulphur	.57	.59	.61	.58	.57
Ultimate:					
Hydrogen	.....	.....	4.99	.....	4.76
Carbon	.....	.....	78.33	.....	80.42
Nitrogen	.....	.....	1.42	.....	1.46
Oxygen	.....	.....	7.94	.....	5.19
Ash	.....	.....	.....	.....	7.58
Sulphur	.....	.....	.....	.....	.59
Calorific value determined (as received): calories	.....	81.35	78.19	.....	.....
Calorific value determined (as received): B. t. u.	.....	146.43	140.74	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Alabama No. 6 (run of mine).

		Test 484.
Size as used:		
Over 1 inch	per cent	23.9
½ inch to 1 inch	do	23.3
¼ inch to ½ inch	do	17.6
Under ¼ inch	do	35.2
Average diameter	inch	.76
Duration of test	hours	9.58
Heating value of coal	B. t. u. per pound dry coal	14,447
Force of draft:		
Under stack damper	inch water	0.82
Above fire	do	.17
Dry coal used per square foot of grate surface per hour	pounds	20.22
Equivalent water evaporated per square foot of water-heating surface per hour	do	4.00
Percentage of rated horsepower of boiler developed		112.2
Water apparently evaporated per pound of coal as fired	pounds	7.96
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	9.64
Per pound of dry coal	do	9.92
Per pound of combustible	do	10.99
Efficiency of boiler, including grate	per cent	66.30
Coal as fired:		
Per indicated horsepower hour	pounds	2.93
Per electrical horsepower hour	do	3.62
Dry coal:		
Per indicated horsepower hour	do	2.85
Per electrical horsepower hour	do	3.52

PRODUCER-GAS TEST.

Alabama No. 6 (run of mine).

Test 155.—Duration of test, 50 hours. Average electrical horsepower, 198.6, average B. t. u. per cubic foot of gas, 143.7, total coal fired, 9,000 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	0.94	0.91	0.85
Developed at switchboard	.91	.89	.82
Per brake horsepower:			
Commercially available	.79	.78	.72
Developed at engine	.77	.75	.70
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.02	1.00	.93
Developed at switchboard	.99	.97	.90
Per brake horsepower:			
Commercially available	.87	.85	.79
Developed at engine	.84	.82	.76

Analyses.

Coal.		*Gas by volume.*	
Moisture	2.44	Carbon dioxide (CO_2)	9.6
Volatile matter	25.96	Carbon monoxide (CO)	19.5
Fixed carbon	64.70	Hydrogen (H_2)	14.9
Ash	6.90	Methane (CH_4)	1.7
Sulphur	.59	Nitrogen (N_2)	54.2
		Ethylene (C_2H_4)	.1

WASHING AND COKING TESTS.

Alabama No. 6 (run of mine).

Washing test 192.—Duration of test, 1¼ hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 r. p. m.; stroke, 2½ inches. Raw coal, 12 tons; washed coal, 10.75 tons, 90 per cent; refuse, 1.25 tons, 10 per cent.

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.
			Per cent.	Per cent reduction.	Per cent
Raw coal, car sample	4353	3.39	6.84	.....	0.59
Washed coal, test 192	4419	6.69	4.76	30	.59
Refuse	.....	8.21	34.92	.....	2.20

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analyses.			
			To refuse.	To total sample.		Ash.		Sulphur.	
						Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	¾	1.36	.....	87	13	2.81	59	0.54	8.5
2	¾	1.42	.....	90	10	3.51	49	.57	4.0
3	¾	1.48	.....	91	9	3.43	50	.53	10.0
4	¾	1.56	.....	94	6	3.75	45	.56	5.0
On refuse (float):[a]									
1	.....	1.35	18.40	1.91	.....	2.81	.....	.89	.....
2	.....	1.40	20.80	2.16	.....	3.48	.....	1.01	.....
3	.....	1.45	20.80	2.16	.....	4.06	.....	1.17	.....
4	.....	1.52	22.30	2.32	.....	5.09	.....	1.06	.....

[a] Figures indicate that finer crushing is advantageous. Loss of "good coal" in the refuse will not exceed 1 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal. It will be noted that in the washing test the sulphur shows the same percentage in the washed coal that it did in the raw coal. This is due to the fact that the reduction of the ash is so much greater than the reduction of the sulphur that the resulting percentage of the sulphur to the washed coal is the same as that of the original sulphur to the raw coal. By the formula $Y=\frac{c-M}{c}$ it is found that 10 per cent of the sulphur in the raw coal was removed in washing.

Coking tests.

		Test 172 (raw).	Test 174 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	40	50
Coal charged	pounds	12,100	11,880
Coke produced	do	8,350	7,800
	per cent	69.01	65.66
Breeze produced	pounds	316	221
	per cent	2.61	1.86
Total yield	do	71.62	67.52

Remarks.—Test 172: Good heavy coke, light-gray and silvery color; metallic ring; cell structure good; breakage good, uniform-sized pieces. Test 174: Good heavy coke, light-gray and silvery color; cell structure rather small; breakage good, uniform-sized pieces; coke better than from raw charge; improvement does not warrant washing, as ash and sulphur are both low.

Analyses.

	Washing test 192, car sample raw coal.	Coking test 172.		Coking test 174.	
		Coal.	Coke.	Coal.	Coke.
Moisture	3.39	3.28	0.46	6.73	0.63
Volatile matter	26.20	25.30	.35	24.84	.27
Fixed carbon	63.57	64.50	89.37	63.57	92.36
Ash	6.84	6.92	9.82	4.86	6.74
Sulphur	.59	.59	.59	.59	.60

ARGENTINA.

ARGENTINA NO. 1.

Coal received from the Province of Mendoza, Argentina, South America, was designated Argentina No. 1.

The coal was taken from two different parts of the mine, the depths being 290 and 110 to 140 feet, respectively, and was used in steaming tests 451, 458, and 485 (on briquets); washing tests 187 and 187a; and briquetting test 180.

CHEMICAL ANALYSES.

Argentina No. 1.

	Car samples.		Steaming tests.[a]		
			451.	458.	485.
Laboratory No	4060	4079			
Air-drying loss		3.00			
Proximate:					
Moisture	7.10	7.67	6.94	16.48	8.75
Volatile matter	19.37	18.39	16.87	17.96	21.45
Fixed carbon	30.97	31.09	26.03	34.23	33.75
Ash	42.56	42.85	50.16	31.33	36.05
Sulphur	.82	1.21	.60	.65	.80
Ultimate:					
Hydrogen		3.40	2.40	3.26	3.41
Carbon		36.55	34.42	46.73	47.51
Nitrogen		.95	.89	1.21	.92
Oxygen		15.04	7.74	10.51	7.77
Ash			53.91	37.51	39.51
Sulphur			.64	.78	.88
Calorific value (as received):					
Determined, calories		3,511			
Determined, B. t. u.		6,320			
Calculated from ultimate analysis, calories		3,504			
Calculated from ultimate analysis, B. t. u.		6,307			

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Argentina No. 1 (run of mine).

		Test 451.	Test 458 (w.).	Test 485 (w.).[a]
Size as used:				
Over 1 inch	per cent	20.5	4.1	See p. 63.
½ inch to 1 inch	do	18.8	10.9	
¼ inch to ½ inch	do	18.7	13.6	
Under ¼ inch	do	42.0	71.4	
Average diameter	inch	0.63	0.32	
Duration of test	hours	8.15	8.88	[b] 2.80
Heating value of fuel	B. t. u. per pound of dry fuel	5,933	8,298	8,235
Force of draft:				
Under stack damper	inch water	0.60	0.76	0.80
Above fire	do	.18	.11	.02
In ash pit (forced draft)	do	.71	.53	.55
Furnace temperature	°F.	.....	[c] 2,014	.....
Dry fuel used per square foot of grate surface per hour	pounds	24.32	21.58	31.34
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	1.22	1.89	2.65
Percentage of rated horsepower of boiler developed		34.2	52.9	74.3
Water apparently evaporated per pound of fuel as fired	pounds	1.96	3.04	3.20
Water evaporated from and at 212° F.:				
Per pound of fuel as fired	do	2.34	3.66	3.87
Per pound of dry fuel	do	2.51	4.38	4.24
Per pound of combustible	do	6.80	7.95	8.52
Efficiency of boiler, including grate	per cent	40.85	50.97	49.72
Fuel as fired:				
Per indicated horsepower hour	pounds	12.09	7.73	7.31
Per electrical horsepower hour	do	14.92	9.54	9.02
Dry fuel:				
Per indicated horsepower hour	do	11.27	6.46	6.67
Per electrical horsepower hour	do	13.91	7.97	8.23

[a] On Renfrow briquets, made in test 180, briquets burned slowly; did not crack open; gave low furnace temperature, and made 4 per cent black smoke. Ash formed on surface of briquets, and tended to form clinker, holding large amount of unconsumed fuel. These lumps were hard to break up. Ash and clinker were white and gray; 60 per cent clinker.

[b] The test was too short for reliable results.

[c] 25 per cent of the reading too low to be read by pyrometer.

WASHING TESTS.

Argentina No. 1 (run of mine).

Preliminary float and sink tests on raw coal.

Float and sink test No.	Size used (inch).	Specific gravity of solution used.	Float (per cent).	Sink (per cent).	Float coal analysis. Ash. Per cent.	Ash. Per cent reduction.	Sulphur. Per cent.	Sulphur. Per cent reduction.
1	¾	1.55	45	55	22.56	47	0.73	12
2	¾	1.60	59	41	24.96	41	.78	12
3	¾	1.65	59	41	27.68	35	.72	12
4	¾	1.70	61	39	27.90	34	.70	12

Washing tests.

	Test 187.	Test 187a.		Test 187.	Test 187a.
Size as used, through screen	2-inch.	2-inch.	Raw coal ... tons	18	5.5
Jig adjustment:			Washed coal ... do	9	3.3
Make or number	Stewart.	Stewart.	Washed coal ... per cent	50	60
Speed ... r. p. m.	35	35	Refuse ... tons	9	2.2
Stroke ... inches	6	6	Refuse ... per cent	50	40

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4060	7.10	42.56	.....	0.82	.....
Washed coal, test 187	4123	17.29	29.67	30	.64	22
Washed coal, test 187a	4344	22.73	34.57	19	.55	33

BRIQUETTING TEST.

Argentina No. 1 (run of mine, washed).

Test 180.—Size as used: Over ¼ inch, 3 per cent; $\frac{1}{10}$ inch to ¼ inch, 8.4 per cent $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 15 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 19.2 per cent; through $\frac{1}{40}$ inch, 54.4 per cent. Briquets very heavy and hard, and gave rough fracture without crumbling when broken, as the coal particles were firmly cemented together and could be handled when warm without breaking. For analyses of briquets see page 61 (steaming test 485).

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ... per cent	84.5
Temperature of briquets ... °F	185	Passed ... do	15.5
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held ... do	91.2
Laboratory No. (see p. 40)	4543	Passed (fines) ... do	8.8
Amount ... per cent	7	Fines through 10-mesh sieve ... do	94.0
Weight of—		Weathering test:	
Fuel briquetted ... pounds	6,000	Time exposed ... days	19
Briquets, average ... do	0.603	Condition	A
Heat value per pound—		Water absorption:	
Fuel as received ... B. t. u.	6,930	In 19 days ... per cent	9.8
Fuel as fired ... do	7,515	Average for first 4 days ... do	1.44
Binder ... do	16,969	Specific gravity (apparent)	1.467

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 180.
Laboratory No	4543	4344	.....
Air-drying loss ... per cent	.....	18.50	4.30
Extracted by CS_2:			
Air-dried ... do	.....	.08	6.38
As received ... do	99.66	.06	6.10
Pitch in briquets, as received ... do	.....	.....	6.06

ARKANSAS.

ARKANSAS NO. 1.[a]

Bituminous coal from Huntington, Sebastian County, on the Frisco System, was designated Arkansas No. 1 B. The coal as worked at a depth of 110 feet at this place averages 7 feet in thickness.

This sample consisted of slack coal. It was loaded under the supervision of John W. Groves, and was used in making washing test 139; coking tests 95, 96, 97, and 100 (washed), and cupola tests 96 and 115.

Two mine samples were taken for chemical analysis. Sample 2586 was cut 900 feet west of the shaft, where the coal measured 7 feet 9 inches in thickness. Sample 2585 was cut one-half mile south of the shaft, where the coal measured 7 feet 3 inches in thickness.

[a] For other tests on coal from this locality made in 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 33, 80, 122, and 148; and Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 42, 198, 345, 1328, 1430.

CHEMICAL ANALYSES.

Arkansas No. 1 B.

		Mine samples.		Car sample.
Laboratory No		2585	2586	2689
Air-drying loss		2.90	3.50	6.70
Proximate:				
Moisture		3.53	4.00	7.49
Volatile matter		16.66	16.82	15.16
Fixed carbon		72.04	72.04	59.38
Ash		7.77	7.14	17.97
Sulphur		1.29	1.32	1.06
Ultimate:				
Hydrogen		.....	.....	4.34
Carbon		.....	.....	65.54
Nitrogen		.....	.....	1.36
Oxygen		.....	.....	9.73
Calorific value (as received):				
Determined	calories	7,787	.....	6,316
	B. t. u.	14,017	.....	11,369
Calculated from ultimate analysis	calories	.....	.....	6,394
	B. t. u.	.....	.....	11,509

WASHING AND COKING TESTS.

Arkansas No. 1 B (slack).

Washing test 139.—Jig used, Stewart. Raw coal, 61,190 pounds; washed, 46,000 pounds; refuse, 15,190 pounds.

Coking tests (on washed coal).

		Test 95.	Test 96.	Test 97.[a]	Test 100.[b]
Size as used		s.	f. c.	f. c.	f. c.
Duration of test	hours	49	71	48	50
Coal charged	pounds	10,000	10,000	10,000	10,000
Coke produced	do	5,832	5,806	6,055	5,976
	per cent	58.32	58.06	60.55	59.76
Breeze produced	pounds	574	1,290	214	391
	per cent	5.74	12.90	2.14	3.91
Total yield	do	64.06	70.96	62.69	63.67

[a] Plus 10 per cent pitch. [b] Plus 15 per cent pitch.

Remarks.—Test 95: Soft and punky; dense; breakage very irregular; large and small lumps. Test 96: Soft and punky with no cell structure; very soft and dense coke. This test was run slowly to save burning fixed carbon and to compare with test 95. Could not get heat, and noncementing action, due to this cause, probably accounts for high breeze. Test 97: Dull-gray color; dense; breakage very bad and irregular; large and small chunks. Test 100: Dull-gray color; soft and punky; dense; practically same as test 97, possibly a little better.

Analyses.

	Washing test 139.		Coking test 95.		Coking test 96.		Coking test 97.		Coking test 100.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	7.49	6.32	10.96	2.89	6.77	1.31	7.80	2.74	5.69	0.18
Volatile matter	15.16	.....	16.66	3.67	15.04	2.44	18.93	1.29	17.34	2.03
Fixed carbon	59.38	.....	66.51	85.23	69.32	84.53	64.92	85.81	68.67	87.26
Ash	17.97	8.62	5.87	8.21	8.87	11.72	8.35	10.16	8.30	10.53
Sulphur	1.06	1.12	1.01	1.25	1.14	1.11	1.08	1.02	1.12	1.07

Cupola tests of coke made from Arkansas No. 1 B coal (washed, plus 10 per cent pitch).

CHARGE.

Cupola test No.	Coke.[a] Test No.	Coke.[a] Specific gravity.	Coke.[a] Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
96	97	1.96	7	93.06	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
115	97	1.96	7	94.44	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

RECORD OF MELT.

Cupola test No.	Blast pressure. On at—	Blast pressure. Maximum.	Iron running in—	Weight of iron. Poured.	Weight of iron. Additional melted.	Weight of iron. Total.	Melting. Time.	Melting. Rate per hour.	Melting. Ratio iron to coke.	Melting. Loss.	Recovered. Iron.	Recovered. Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
96	3.50 p. m.	7	8	1,663	319	1,982	36	3,303	5.33	9.60	730	58
115	3.33 p. m.	7	14	1,648	404	2,052	25	4,925	5.58	10.70	627	62

LADLE RECORD.

Ladle No.	Test 96. Pounds.	Test 96. Time (p. m.).	Test 115. Pounds.	Test 115. Time (p. m.).	Ladle No.	Test 96. Pounds.	Test 96. Time (p. m.).	Test 115. Pounds.	Test 115. Time (p. m.).
1	64	4.02	106	3.57	12	108	4.22	100	4.10½
2	78	4.07	107	3.57½	13	115	4.22½	126	4.11
3	85	4.07½	104	3.58	14	61	4.23	95	4.11½
4	65	4.12	110	4.05	15	97	4.24	94	4.12
5	73	4.12½	112	4.06	16	112	4.24½		
6	41	4.13	111	4.06½	17	58	4.25		
7	79	4.13½	129	4.07	18	77	4.28		
8	70	4.14	107	4.07½	19	98	4.28½		
9	70	4.19	128	4.08	20	55	4.29		
10	75	4.19½	111	4.09	21	80	4.31		
11	61	4.20	108	4.10	22	41	4.34		

[a] Phosphorus in coke, 0.0135 per cent; sulphur in ash, 0.05 per cent.

Remarks.—Test 96: Iron hot. Test 115: Iron hot; bed burned out and charges hung; bottom had to be dropped after the fifteenth ladle.

ARKANSAS NO. 7.

Bituminous coal from a mine located 4 miles southwest of Midland, Sebastian County, on the Midland Valley Railroad, was designated Arkansas No. 7. The coal as worked at a depth of 190 feet at this place averages 7 feet 6 inches in thickness.

Two lots of coal were shipped from this mine under the supervision of John W. Groves. Arkansas No. 7 A consisted of domestic lump which had passed over a 2-inch perforated screen. It was used in making steaming tests 293 and 294 and producer-gas test 96. Arkansas No. 7 B consisted of slack coal which had passed through a 2-inch

perforated screen. It was used in making washing test 141, coking tests 104 and 105, cupola tests 116 and 142, and briquetting test 106.

Two mine samples were taken for chemical analysis. Sample 2593 was cut 950 feet northwest of the foot of the slope, where the coal measured 8 feet in thickness. Sample 2594 was taken 900 feet northeast of the foot of the slope, where the coal measured 7 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Arkansas No. 7.

	Mine samples.		Car samples.		Steaming tests.[a]	
			A.	B.	293	294
Laboratory No.	2593	2594	2688	2722	.....	.....
Air-drying loss	3.50	4.90	4.90	5.90	.....	.....
Proximate:						
Moisture	3.97	5.38	5.47	6.89	5.41	5.55
Volatile matter	16.86	16.02	16.27	15.23	16.10	15.88
Fixed carbon	73.26	69.76	66.57	62.88	68.34	67.40
Ash	5.91	8.84	11.69	15.00	10.15	11.17
Sulphur	1.53	3.20	2.02	2.24	1.81	1.86
Ultimate:						
Hydrogen	.....	.....	4.33	4.44	4.03	3.97
Carbon	.....	.....	72.63	68.28	78.49	77.47
Nitrogen	.....	.....	1.26	1.26	1.36	1.34
Oxygen	.....	.....	8.07	8.78	3.48	3.42
Ash	.....	.....	.....	.....	10.73	11.83
Sulphur	.....	.....	.....	.....	1.91	1.97
Calorific value (as received):						
Determined, Calories	7,909	.....	7,050	6,700	.....	.....
Determined, B. t. u.	14,236	.....	12,690	12,060	.....	.....
Calculated from ultimate analysis, Calories	.....	.....	7,058	6,718	.....	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	12,704	12,092	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Arkansas No. 7 A (lump).

	Test 293.	Test 294.
Size as used:		
Over 1 inch ... per cent	6.3	7.0
½ inch to 1 inch ... do	11.9	8.8
¼ inch to ½ inch ... do	18.5	14.1
Under ¼ inch ... do	63.3	70.1
Duration of test ... hours	9.8	10.0
Heating value of coal ... B. t. u. per pound of dry coal	13,705	13,531
Force of draft:		
Under stack damper ... inch water	0.62	0.62
Above fire ... do	.15	.....
In ash pit (forced draft) ... do	.....	.25
Furnace temperature ... °F	1,972	2,060
Dry coal used per square foot of grate surface per hour ... pounds	13.71	17.34
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	2.60	3.06
Percentage of rated horsepower of boiler developed	72.8	85.7
Water apparently evaporated per pound of coal as fired ... pounds	7.55	7.01
Water evaporated from and at 212° F.:		
Per pound of coal as fired ... do	8.97	8.35
Per pound of dry coal ... do	9.48	8.84
Per pound of combustible ... do	11.02	10.34
Efficiency of boiler, including grate ... per cent	66.80	63.09
Coal as fired:		
Per indicated horsepower hour ... pounds	3.15	3.39
Per electrical horsepower hour ... do	3.89	4.18
Dry coal:		
Per indicated horsepower hour ... do	2.98	3.20
Per electrical horsepower hour ... do	3.68	3.95

PRODUCER-GAS TEST.

Arkansas No. 7 A (lump).

Test 96.—Size as used: Over 1 inch, 28 per cent; ½ inch to 1 inch, 10 per cent; ¼ inch to ½ inch, 15 per cent; under ¼ inch, 47 per cent. Duration of test, 50 hours; average electrical horsepower, 137.3; average B. t. u. per cubic foot of gas, 125.5; total coal fired, 12,900 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.06	1.97	1.72
Developed at switch board	1.88	1.80	1.57
Per brake horsepower:			
Commercially available	1.75	1.67	1.46
Developed at engine	1.60	1.53	1.34
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.24	2.14	1.87
Developed at switch board	2.04	1.96	1.71
Per brake horsepower:			
Commercially available	1.90	1.82	1.59
Developed at engine	1.74	1.66	1.43

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.27	Carbon dioxide (CO_2)	14.8
Volatile matter	16.04	Carbon monoxide (CO)	12.1
Fixed carbon	67.43	Hydrogen (H_2)	16.1
Ash	12.26	Methane (CH_4)	1.6
Sulphur	2.15	Nitrogen (N_2)	55.4

WASHING AND COKING TESTS.

Arkansas No. 7 B (slack).

Washing test 141.—Jig used, Stewart. Raw coal, 50,000 pounds; washed, 38,000 pounds; refuse, 12,000 pounds.

Coking tests (on washed coal).

		Test 104.	Test 105.[a]
Size as used		s.	f. c.
Duration of test	hours	67	57
Coal charged	pounds	10,000	10,000
Coke produced	do	2,730	4,868
	per cent	27.30	48.68
Breeze produced	pounds	3,750	1,604
	per cent	37.50	16.04
Total yield	do	64.80	64.72

[a] Plus 5 per cent pitch.

Remarks.—Test 104: Dull-gray color; very soft and light weight; breaking up in oven, on pulling, into large and small chunks; has appearance of being cemented together after volatile was driven off; practically no cell structure; high yield of breeze due to noncementing action, all volatile, as analysis shows, being driven off finely crushing before charging. Test 105: Soft and punky; very dense; dull and not gray color; physically better than coke from coal without pitch; percentage of breeze very high; breaks into large and small chunks; better weight than coke in test 104, but light.

Analyses.

	Washing test 141.		Coking test 104.		Coking test 105.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	6.89	* 6.45	6.98	0.13	7.52	0.67
Volatile matter	15.23	.....	14.86	.53	16.66	.85
Fixed carbon	62.88	.....	70.97	89.72	68.85	89.14
Ash	15.00	7.19	7.19	9.62	6.97	9.34
Sulphur	2.24	1.89	1.78	1.70	1.65	1.60

Cupola tests of coke made from Arkansas No. 7 B coal (washed, plus 5 per cent pitch).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron. to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
116	105	1.97	7	99.9	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750
142	105	197	7	93.05	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750

[a] Phosphorus in coke, 0.0135 per cent; sulphur in ash, 0.07 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
116	10.41 a. m.	7	12	772	318	1,090	33	1,982	3.25	3.13	1,816	95
142	10.55 a. m.	7	6	1,637	399	2,036	35	3,490	5.72	7.60	736	74

LADLE RECORD.

Ladle No.	Test 116.		Test 142.		Ladle No.	Test 116.		Test 142.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).	Pounds.	Time (a. m.).
1	83	11.05	81	11.07	12	.....	.....	83	11.24
2	94	11.06	87	11.10	13	.....	.....	64	11.25
3	74	11.11	75	11.10½	14	.....	.....	104	11.25½
4	90	11.12	73	11.12	15	.....	.....	77	11.26
5	97	11.12½	70	11.12½	16	.....	.....	55	11.28
6	23	11.13	80	11.17	17	.....	.....	98	11.28½
7	65	11.17	75	11.17½	18	.....	.....	72	11.29
8	72	11.17½	80	11.18	19	.....	.....	58	11.33
9	89	11.18	84	11.19	20	.....	.....	63	11.33½
10	61	11.25	61	11.23	21	.....	.....	58	11.34
11	24	11.26	99	11.23½	22	.....	.....	40	11.36

Remarks.—Test 116: Iron hot; charges hung and bottom dropped after eleventh ladle. Test 142: Iron medium temperature.

BRIQUETTING TEST.

Arkansas No. 7 B (washed slack).

Test 106.—Machine used, English. Temperature of briquets, 179.6° F. Kind of binder,[a] coal-tar pitch; laboratory No. 2735 (see p. 40). Amount of binder, 4, 5, and 6 per cent. Weight of fuel briquetted, 4,000 pounds.

Briquets made with 4, 5, and 6 per cent of binder were equally satisfactory, with hard, fine structure, glossy fracture, and well-molded, sharp edges. In the drop test with 4 per cent binder the 1-inch screen held 31.4 per cent and passed 68.6 per cent. In the weathering test all binders were exposed 80 days; condition for the 4 per cent C, for the others B.

ARKANSAS NO. 8.

Semianthracite coal from Spadra, Johnson County, on the St. Louis, Iron Mountain and Southern Railway, was designated Arkansas No. 8. The coal as worked at a depth of 87 feet at this place averages 2 feet 10 inches in thickness.

The sample, which was shipped under the supervision of W. J. Von Borries, consisted of No. 4 coal screened on a 1¼-inch round perforated screen. It was used in making steaming tests 297, 308, and (washed coal) 309; producer-gas test 95, and washing test 144.

Two mine samples were taken for chemical analysis. Sample 2587 was cut 1,300 feet northeast of the shaft, where the coal measured 2 feet 11 inches in thickness. Sample 2588 was cut 1,650 feet northwest of the shaft, where the coal measured 2 feet 11½ inches in thickness.

CHEMICAL ANALYSES.

Arkansas No. 8.

	Mine samples.		Car sample.	Steaming tests.[b]		
				297.	308.	309.
Laboratory number	2587	2588	2744			
Air-drying loss	2.50	2.10	4.40			
Proximate:						
Moisture	3.12	2.72	5.19	3.24	5.93	5.93
Volatile matter	11.39	11.20	10.49	9.90	11.21	10.79
Fixed carbon	77.03	77.71	70.31	71.93	74.80	75.43
Ash	8.46	8.37	14.01	14.93	8.06	7.85
Sulphur	1.84	2.78	2.05	2.46	2.08	2.03
Ultimate:						
Hydrogen			3.78	3.34	3.63	3.64
Carbon			72.43	75.46	82.06	82.30
Nitrogen			.51	.53	.57	.59
Oxygen			7.22	2.70	2.96	2.97
Ash				15.43	8.57	8.34
Sulphur				2.54	2.21	2.16
Calorific value (as received):						
Determined, calories	7,607		6,922			
Determined, B. t. u.	13,793		12,460			
Calculated from ultimate analysis, calories			6,891			
Calculated from ultimate analysis, B. t. u.			12,404			

[a] The flowing point of the binder used was 188.8° F., and 58.56 per cent of the sample as received was extracted by CS_2. All other data concerning this binder were lost in the fire.

[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Arkansas No. 8 (washed).

	Test 287.	Test 308.	Test 309.
Size as used:			
Over 1 inch ... per cent	46.6	24.0	15.4
½ inch to 1 inch ... do	16.0	17.0	14.8
¼ inch to ½ inch ... do	8.7	18.0	18.5
Under ¼ inch ... do	28.7	41.0	15.3
Duration of test ... hours	9.72	5.03	5.03
Heating value of coal ... B. t. u. per pound of dry coal	13,000	14,125	14,153
Force of draft:			
Under stack damper ... inch water	0.63	0.72	0.62
Above fire ... do	.....	(a)	.....
In ash pit ... do	1.03	.....	(b)
Furnace temperature ... °F	1,964	1,961	2,403
Dry coal used per square foot of grate surface per hour ... pounds	18.55	16.13	22.12
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.03	2.89	3.79
Percentage of rated horsepower of boiler developed	85.0	80.9	106.3
Water apparently evaporated per pound of coal as fired ... pounds	6.69	7.01	6.69
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	7.93	8.42	8.08
Per pound of dry coal ... do	8.19	8.96	8.59
Per pound of combustible ... do	10.49	10.82	10.06
Efficiency of boiler, including grate ... per cent	60.84	61.26	58.61
Coal as fired:			
Per indicated horsepower hour ... pounds	3.57	3.36	3.50
Per electrical horsepower hour ... do	4.40	4.15	4.32
Dry coal:			
Per indicated horsepower hour ... do	3.45	3.16	3.29
Per electrical horsepower hour ... do	4.26	3.90	4.07

a Natural draft. b Forced draft.

PRODUCER-GAS TEST.

Arkansas No. 8.

Test 95.—Size as shipped, 4 inches; size as used: Over 1 inch, 68 per cent; ½ inch to 1 inch, 13 per cent; ¼ inch to ½ inch, 6 per cent; under ¼ inch, 13 per cent. Duration of test, 26 hours; average electrical horsepower, 177.2; average B. t. u. per cubic foot of gas, 130; total coal fired, 8,550 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.96	1.90	1.60
Developed at switchboard	1.86	1.81	1.52
Per brake horsepower:			
Commercially available	1.66	1.62	1.36
Developed at engine	1.58	1.54	1.29
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.13	2.07	1.74
Developed at switchboard	2.02	1.97	1.65
Per brake horsepower:			
Commercially available	1.81	1.76	1.48
Developed at engine	1.72	1.67	1.40

Analyses.

Coal.

Moisture	2.74
Volatile matter	9.70
Fixed carbon	71.95
Ash	15.61
Sulphur	2.45

Gas by volume.

Carbon dioxide (CO_2)	11.3
Carbon monoxide (CO)	15.9
Hydrogen (H_2)	14.7
Methane (CH_4)	1.0
Nitrogen (N_2)	56.7
Oxygen (O_2)	.2
Ethylene (C_2H_4)	.2

WASHING TESTS.

Arkansas No. 8.

Test 144.—Size as shipped and used, No. 4 nut. Jig used, Stewart. Raw coal, 23,000 pounds; washed, 19,570 pounds; refuse, 3,430 pounds.

Analyses.—Raw coal: See car sample No. 2744 (p. 69). Washed coal: Moisture, 5.03; ash, 7.85; sulphur, 2.03.

ARKANSAS NO. 9.

Bituminous coal from Bonanza, Sebastian County, on the Frisco System, was designated Arkansas No. 9. The coal, as worked at a depth of 350 feet at this place, averages 3 feet 3 inches in thickness.

This sample consisted of slack coal through a 1⅛-inch bar screen. It was shipped under the supervision of John W. Groves, and the following tests were made: Washing test, 140; coking tests, 98, 99, 101, 102, and 103 on washed coal; and cupola tests 95 and 117.

Two mine samples were taken for chemical analysis. Sample 2599 was cut 1,400 feet southeast of the shaft, where the coal measured 3 feet 1½ inches in thickness. Sample 2600 was cut 1,100 feet west of the shaft, where the coal measured 3 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Arkansas No. 9.

	Mine samples.		Car sample.
Laboratory No	2599	2600	2690
Air-drying loss	1.70	1.80	4.20
Proximate:			
Moisture	1.99	2.12	5.26
Volatile matter	15.90	16.17	14.71
Fixed carbon	75.05	75.01	55.22
Ash	7.06	6.70	24.81
Sulphur	1.05	1.78	1.00
Ultimate:			
Hydrogen			3.91
Carbon			59.87
Nitrogen			1.23
Oxygen			9.18
Calorific value (as received):			
Determined, calories	7,826		5,806
Determined, B. t. u.	14,087		10,451
Calculated from ultimate analysis, calories			5,812
Calculated from ultimate analysis, B. t. u.			10,462

WASHING AND COKING TESTS.

Arkansas No. 9 (slack).

Washing test 140.—Jig used, Stewart. Raw coal, 77,300 pounds; washed, 57,350 pounds; refuse, 19,950 pounds.

Coking tests (on washed coal).

	Test 98.	Test 99.	Test 101.[a]	Test 102.[b]	Test 103.[c]
Size as shipped, inches	1⅛	1⅛	1⅛	1⅛	1⅛
Size as used, do	f. c.	1⅛	f. c.	f. c.	1⅛
Duration of test, hours	28	24	39	43	46
Coal charged, pounds				10,000	10,000
Coke produced, do				6,252	5,107
Coke produced, per cent				62.52	51.07
Breeze produced, pounds				458	1,693
Breeze produced, per cent				4.58	16.93
Total yield, do				67.10	68.00

[a] Plus 3.44 per cent asphalt. [b] Plus 10 per cent pitch. [c] Plus 5 per cent pitch.

Remarks.—Test 98: No coke produced; ashed down about 5 inches. Test 99 on washed slack not crushed gave same result; no coke. Test 101: No coke produced; ashed down about 6 inches. Test 102: Dull-gray color; soft and punky; dense with good weight; breakage very irregular, large and small chunks. Test 103: Very soft and punky; has appearance of being cemented together after volatile was driven off; high yield of breeze due to noncementing action, all volatile being driven off; 5 per cent pitch, not enough, as results from test 102, 10 per cent pitch, show.

Analyses.

	Washing test 140.		Coking test 98 (coal).	Coking test 101 (coal).	Coking test 102.		Coking test 103.	
	Raw coal.	Washed coal.			Coal.	Coke.	Coal.	Coke.
Moisture	5.26	7.78	7.43	6.30	5.60	0.30	5.76	0.33
Volatile matter	14.71	.....	13.84	14.74	17.22	.81	14.84	.80
Fixed carbon	55.22	.....	65.55	65.01	64.03	81.48	66.63	83.70
Ash	24.81	14.30	13.18	13.95	13.15	17.41	12.77	15.17
Sulphur	1.00	.98	.96	.98	1.01	1.07	1.02	1.07

Cupola tests of coke made from Arkansas No. 9 coal, washed, plus 10 per cent pitch.

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
95	102	2.04	7	88.89	Coke	210	55	55	55	55	430
					Pig iron	630	405	405	405	405	2,250
					Scrap	210	135	135	135	135	750
117	102	2.04	7	98.61	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750

RECORD OF MELT.

Cupola test. No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
95	10.50 a. m.	7	12	679	354	1,033	28	2,214	3.56	5.07	1,815	140
117	8.02 a. m.	6½	16	1,005	288	1,293	25	3,103	4.01	8.10	1,464	108

LADLE RECORD.

Ladle No.	Test 95.		Test 117.		Ladle No.	Test 95.		Test 117.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).	Pounds.	Time (a. m.).
1	82	11.16	78	8.26	10	61	11.30	77	8.38
2	50	11.19	52	8.31	11	.....	.....	54	8.38½
3	92	11.19½	53	8.31½	12	.....	.....	55	8.39
4	53	11.20	70	8.32	13	.....	.....	64	8.39½
5	58	11.26	67	8.32½	14	.....	.....	70	8.41½
6	72	11.26½	37	8.34	15	.....	.....	48	8.42
7	91	11.27	60	8.34½	16	.....	.....	45	8.42½
8	61	11.29	66	8.35	17	.....	.....	26	8.43
9	59	11.29½	83	8.35½					

[a] Phosphorus in coke, 0.0329 per cent; sulphur in ash, 0.17 per cent.

Remarks.—Test 95: Iron cold and dull. Test 117: Iron hot and fluid.

ARKANSAS NO. 10.

Lignite from a mine located 7 miles west of Lester, Ouachita County, on the St. Louis, Iron Mountain and Southern Railway, was designated Arkansas No. 10. The lignite, as worked from the outcrop at this place, averages 5 feet 6 inches in thickness.

This sample consisted of run-of-mine lignite and was shipped under the supervision of John W. Groves. It was used in steaming test 340 and producer-gas test 91.

Two mine samples were taken for chemical analysis. Sample 2647 was taken 300 feet from the drift mouth, where the coal measured 6 feet 6 inches in thickness. Sample 2648 was taken in the air course 300 feet from the drift mouth, where the coal measured 5 feet in thickness.

CHEMICAL ANALYSES.

Arkansas No. 10.

	Mine samples.		Car sample.[a]	Steaming test 340.[b]
Laboratory No.	2647	2648	2726	.....
Air-drying loss	32.60	35.70	25.10	.....
Proximate:				
Moisture	39.50	41.25	39.43	38.75
Volatile matter	25.35	27.96	26.49	25.82
Fixed carbon	22.57	22.98	24.37	22.20
Ash	12.58	7.81	9.71	13.23
Sulphur	.53	.50	.49	.57
Ultimate:				
Hydrogen	.....	.....	6.98	4.00
Carbon	.....	.....	36.33	55.88
Nitrogen	.....	.....	.68	1.04
Oxygen	.....	.....	45.81	16.55
Ash	.....	.....	.....	21.60
Sulphur	.....	.....	.....	.93
Calorific value (as received):				
Determined, calories	3,265	.....	3,531	.....
Determined, B. t. u.	5,877	.....	6,356	.....
Calculated from ultimate analysis, calories	.....	.....	3,377	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	6,079	.....

[a] Car sample figured from producer-gas test 91.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Arkansas No. 10 (run of mine).

		Test 340.
Size as used:		
3 inch to 1½ inch	per cent	36.3
1½ inch to 1 inch	do	8.1
1 inch to ¾ inch	do	19.3
¾ inch to ½ inch	do	15.0
Under ½ inch	do	21.3
Duration of test	hours	9.0
Heating value of fuel	B. t. u. per pound dry fuel	9,549
Force of draft:		
Under stack damper	inch water	.82
Above fire	do	[a] .12
Dry fuel used per square foot of grate surface per hour	pounds	35.33
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.71
Percentage of rated horsepower of boiler developed		[b] 104.0
Water apparently evaporated per pound of fuel as fired	pounds	2.99

[a] Forced draft. [b] Test represents maximum capacity.

STEAMING TEST—Continued.

Arkansas No. 10 (run of mine).

		Test 340.
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	pounds	3.59
Per pound of dry fuel	do	5.86
Per pound of combustible	do	7.60
Efficiency of boiler, including grate	per cent	59.26
Fuel as fired:		
Per indicated horsepower hour	pounds	7.88
Per electrical horsepower hour	do	9.72
Dry fuel:		
Per indicated horsepower hour	do	4.83
Per electrical horsepower hour	do	5.96

PRODUCER-GAS TEST.

Arkansas No. 10 (run of mine).

Test 91.—Duration of test, 18 hours. Average electrical horsepower, 128.7. Average B. t. u. per cubic foot of gas, 125.3. Total coal fired, 8,250 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	3.87	2.34	1.96
Developed at switch board	3.56	2.16	1.81
Per brake horsepower:			
Commercially available	3.29	1.99	1.67
Developed at engine	3.03	1.83	1.54
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	4.41	2.67	2.24
Developed at switch board	4.07	2.46	2.07
Per brake horsepower:			
Commercially available	3.75	2.27	1.91
Developed at engine	3.45	2.09	1.76

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	13.5
Carbon monoxide (CO)	14.0
Hydrogen (H_2)	9.2
Methane (HC_4)	2.4
Nitrogen (N_2)	60.9

ARKANSAS NO. 13.

Bituminous slack from mines at Denning, on the St. Louis, Iron Mountain and Southern Railway, was designated Arkansas No. 13.

Three cars (100 tons) of this coal were shipped by the operator uninspected, and used for briquetting tests 164†[b], 214, and 221.

[a] For analysis of coal see p. 73 (car sample No. 2726).

[b] Briquets from this test were used in water-gas machine test. (See p. 44.)

CHEMICAL ANALYSES.

Arkansas No. 13.

	Car sample.	Briquetting tests.[a] 164†.	214.	221.
Labratory No.	3798	.....	.....	4626
Air-drying loss	1.70	.....	.....	0.80
Proximate:				
Moisture	2.91	1.49	1.05	1.76
Volatile matter	12.65	15.11	16.50	15.98
Fixed carbon	66.93	68.30	68.84	67.30
Ash	17.51	15.10	13.61	14.96
Sulphur	.....	2.58	2.48	2.29
Ultimate:				
Hydrogen	3.60	3.84	3.85	3.84
Carbon	70.88	75.03	75.63	75.65
Nitrogen	1.17	1.35	1.24	1.24
Oxygen	3.72	1.83	1.70	1.71
Ash	17.51	15.33	15.23	15.23
Sulphur	3.12	2.62	2.33	2.33
Calorific value (as received):				
Determined, calories	6,840	.....	.....	7,181
Determined, B. t. u.	12,312	.....	.....	12,926
Calculated from ultimate analysis, calories	6,876	.....	.....	.....
Calculated from ultimate analysis, B. t. u.	12,377	.....	.....	.....

[a] Proximate analysis of coal as received; ultimate analysis on dry basis.

BRIQUETTING TESTS.

Arkansas No. 13 (slack).

Tests 164†, 214, 221.—Size as used: Over ¼ inch, 1.4 per cent; $\frac{1}{10}$ inch to ¼ inch, 6.2 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 10.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 15.8 per cent; through $\frac{1}{40}$ inch, 66 per cent. There was no apparent difference in appearance between briquets made with 7 and 8 per cent binder. Both were excellent briquets, with hard, smooth surface, clean fracture, easily handled, and piled while warm. Less binder could be used with increased pressure. The briquets with 8 per cent binder made less slack in handling when cold. Those with 9 per cent binder were not satisfactory, as the pitch used had a much higher melting point and could not be successfully worked at the pressure available.

	Test 164†.[a]	Test 214.	Test 221.
Details of manufacture:			
Machine used	Renf.	Renf.	Renf.
Temperature of briquets, °F.	185	185	185
Binder—			
Kind	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	3885	3885, 4683	4625
Amount, per cent	7	8	9
Weight of—			
Fuel briquetted, pounds	140,000	40,000	5,000
Briquets, average, do.	0.451	0.464	0.489
Heat value per pound—			
Fuel as received, B. t. u.	12,312	12,312	12,312
Fuel as fired, do.	12,917	12,926	.....
Binder, do.	16,870	16,812	16,576
Drop test (1-inch screen):			
Held, per cent	54.5	49.5	51.0
Passed, do.	45.5	50.5	49.0
Tumbler test (1-inch screen):			
Held, do.	79.0	81.5	86.0
Passed (fines), do.	21.0	18.5	14.0
Fines through 10-mesh sieve, do.	87.7	87.3	88.9
Weathering test:			
Time exposed, days	106	.....	.....
Condition	B.	.....	.....
Water absorption:			
In 19 days, per cent	17.2	.....	.....
In 13 days, do.	.....	13.6	10.2
Average for first 5 days, do.	2.50	2.36	1.72
Specific gravity (apparent)	1.130	1.161	1.247

[a] Briquets from this test were used in water-gas machine test (p. 44).

Extraction analyses.

	Pitches.			Fuel.	Briquets.	
					Test 164.	Tests 214, 221.
Laboratory No.	3885	4625	4083	3798	4892	4626
Air-drying loss, per cent				1.70	0.70	0.80
Extracted by CS_2:						
Air dried do				.10	5.80	6.34
As received do	95.20	90.56	89.31	.09	5.76	6.29
Pitch in briquets, as received do					5.97	6.63

FLORIDA.

FLORIDA NO. 1.

Peat from a bog located at Orlando, Orange County, on the Seaboard Air Line Railway, was designated Florida No. 1.

This sample consisted of machined peat made by a commercial process and sun dried, and was used in steaming test 386 and producer-gas test 117.

By this process the peat first passes through a condenser, which disintegrates the material and destroys the fiber. From the condenser the peat is elevated to a molding machine, consisting of a cylinder and two vertical molding wheels. Through the cylinder passes a vertical shaft to which are attached revolving arms set in a screw form. Between these arms perforated plates are set. The peat passing into the top of the cylinder is forced down through the plates to the molding wheel. From the molding wheel the bricks, which are 8 by 4 by 2½ inches, are dropped on boards which are being continually pushed under the machine by a link-belt carrier. These boards, containing 6 bricks each, are loaded on wagons, 50 to the load, and are hauled to the drying ground, where they are allowed to lose from 60 to 75 per cent of their moisture content.

Two samples were taken for analysis. Sample 3268 is raw peat just as it comes from the bog, and sample 3269 is one of the bricks as it came from the machine before delivery to the drying ground.

CHEMICAL ANALYSES.

Florida No. 1.

	Bog samples.		Car sample.[a]	Steaming test 386.[b]
Laboratory No.	3268	3269	3270	.....
Air-drying loss	91.70	84.70	9.00	.....
Proximate:				
Moisture	92.41	88.40	21.00	17.21
Volatile matter	4.68	7.28	51.72	51.01
Fixed carbon	2.58	3.57	22.11	24.85
Ash	.33	.75	5.17	6.93
Sulphur	.05	.08	.45	.49
Ultimate:				
Hydrogen	.....	.....	6.51	5.18
Carbon	.....	.....	46.57	57.77
Nitrogen	.....	.....	2.33	2.89
Oxygen	.....	.....	38.97	25.20
Ash	.....	.....	.....	8.37
Sulphur	.....	.....	.....	.59
Calorific value (as received):				
Determined, calories	.....	.....	4,515	.....
Determined, B. t. u.	.....	.....	8,127	.....
Calculated from ultimate analysis, calories	.....	.....	4,338	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	7,808	.....

[a] Figured from sample taken from producer-gas test 117.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Florida No. 1 (compressed peat).

		Test 386.
Duration of test	hours	4.07
Heating value of fuel	B. t. u. per pound of dry fuel	10,082
Force of draft:		
Under stack damper	inch water	0.69
Above fire	do	.13
Furnace temperature	°F.	2,457
Dry fuel used per square foot of grate surface per hour	pounds	33.49
Equivalent water evaporated per square foot of water-heating surface per hour	do	4.04
Percentage of rated horsepower of boiler developed		113.2
Water apparently evaporated per pound of fuel as fired	pounds	4.27
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	do	5.00
Per pound of dry fuel	do	6.04
Per pound of combustible	do	6.63
Efficiency of boiler, including grate	per cent	57.85
Fuel as fired:		
Per indicated horsepower hour	pounds	5.66
Per electrical horsepower hour	do	6.98
Dry fuel:		
Per indicated horsepower hour	do	4.68
Per electrical horsepower hour	do	5.78

PRODUCER-GAS TEST.

Florida No. 1 (compressed peat).

Test 117.—Duration of test, 50 hours. Average electrical horsepower, 205. Average B. t. u. per cubic foot of gas, 175.2. Total fuel fired, 29,250 pounds.

	Peat as fired.	Dry peat.	Combustible.
Peat consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.98	2.35	2.20
Developed at switchboard	2.85	2.25	2.11
Per brake horsepower:			
Commercially available	2.53	2.00	1.87
Developed at engine	2.43	1.92	1.79
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	3.16	2.50	2.33
Developed at switchboard	3.03	2.39	2.24
Per brake horsepower:			
Commercially available	2.69	2.12	1.98
Developed at engine	2.57	2.03	1.90

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	12.4
Carbon monoxide (CO)	21.0
Hydrogen (H_2)	18.5
Methane (CH_4)	2.2
Nitrogen (N_2)	45.5
Ethylene (C_2H_4)	4

GEORGIA.

GEORGIA NO. 1.

Bituminous coal from the Little River bed at Menlo, Chattooga County, on the Chattanooga Southern Railway, was designated Georgia No. 1. This coal, as worked from the outcrop at this place, averages 1 foot 11 inches in thickness.

One sample, shipped under the supervision of A. K. Adams, consisted of lump coal over a 1¼-inch perforated stationary screen, and was used in steaming test 481 and coking test 173.

Two mine samples were taken for chemical analysis. Sample 4155 was taken 1,600 feet east of the opening, where the coal measured 2 feet in thickness. Sample 4156 was taken 2,800 feet east of the opening, where the coal measured 1 foot 11 inches in thickness.

CHEMICAL ANALYSES.

Georgia No. 1.

	Mine samples.		Car sample.	Steaming test 481.[b]
Laboratory No.	4155	4156	4320	.....
Air-drying loss	1.90	2.30	3.20	.....
Proximate:				
Moisture	2.40	2.85	3.80	3.11
Volatile matter	18.17	17.14	15.88	16.90
Fixed carbon	70.09	72.17	65.83	62.77
Ash	9.34	7.84	14.49	17.22
Sulphur	1.12	.67	1.27	1.29
Ultimate:				
Hydrogen	.....	.....	4.32	3.92
Carbon	.....	.....	70.59	70.99
Nitrogen	.....	.....	1.09	1.09
Oxygen	.....	.....	8.24	4.90
Ash	.....	.....	.....	17.77
Sulphur	.....	.....	.....	1.33
Calorific value determined (as received) calories	.....	7,888	7,106	.....
Calorific value determined (as received) B. t. u.	.....	14,198	12,791	.....

[a] For analysis of the peat used, see p. 77 (car sample 3270).
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Georgia No. 1.

		Test 481.
Size as used:		
Over 1 inch	per cent	37.9
½ inch to 1 inch	do	15.8
¼ inch to ½ inch	do	14.5
Under ¼ inch	do	31.8
Average diameter	inch	0.89
Duration of test	hours	9.47
Heating value of coal	B. t. u. per pound dry coal	12,865
Force of draft:		
Under stack damper	inch water	0.81
Above fire	do	.19
Dry coal used per square foot of grate surface per hour	pounds	22.32
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.99
Percentage of rated horsepower of boiler developed		111.8
Water apparently evaporated per pound of coal as fired	pounds	7.20
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.67
Per pound of dry coal	do	8.95
Per pound of combustible	do	11.39
Efficiency of boiler, including grate	per cent	67.18
Coal as fired:		
Per indicated horsepower hour	pounds	3.26
Per electrical horsepower hour	do	4.03
Dry coal:		
Per indicated horsepower hour	do	3.16
Per electrical horsepower hour	do	3.90

COKING TEST.

Georgia No. 1.

Test 173.—Size as shipped, 1½ inches and larger; as used, raw, finely crushed. Duration of test, 58 hours; coal charged, 12,180 pounds; coke produced, 8,100 pounds, 66.50 per cent; breeze produced, 549 pounds, 4.51 per cent; total yield, 71.01 per cent. Poor, dense coke. Large pieces of irregular size. Washing would probably improve and make fair grade of coke.

Analyses.

	Coal.	Coke.
Moisture	3.35	0.45
Volatile matter	16.54	.35
Fixed carbon	66.07	81.69
Ash	14.04	17.51
Sulphur	1.29	1.00

ILLINOIS.

ILLINOIS NO. 7.[a]

Screened nut coal from a mine near Collinsville was designated Illinois No. 7 E, and was used in steaming test 516 and briquetting test 244†.

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 57-60.

CHEMICAL ANALYSES.

Illinois No. 7 E.

	Steaming test 516.[a]	Briquetting test 244†.[b]		Steaming test 516.[a]	Briquetting test 244†.[b]
Proximate:			Ultimate:		
Moisture	14.47	6.06	Hydrogen	3.84	3.57
Volatile matter	28.14	30.09	Carbon	56.08	59.48
Fixed carbon	35.16	40.34	Nitrogen	.91	.83
Ash	22.23	23.51	Oxygen	8.82	5.67
Sulphur	3.73	5.09	Ash	25.99	25.03
			Sulphur	4.36	5.42

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TEST.

Illinois No. 7 E.

		Test 516.
Size as used:		
Over 1 inch	per cent	4.8
½ inch to 1 inch	do	24.7
¼ inch to ½ inch	do	25.1
Under ¼ inch	do	45.4
Average diameter	inch	0.47
Duration of test	hours	7.85
Heating value of coal	B. t. u. per pound dry coal	10,283
Force of draft:		
Under stack damper	inch water	0.87
Above fire	do	.13
In ash pit		.31
Dry coal used per square foot of grate surface per hour	pounds	31.99
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.70
Percentage of rated horsepower of boiler developed		103.7
Water apparently evaporated per pound of coal as fired	pounds	4.09
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	4.95
Per pound of dry coal	do	5.79
Per pound of combustible	do	8.21
Efficiency of boiler, including grate	per cent	54.38
Coal as fired:		
Per indicated horsepower hour	pounds	5.71
Per electrical horsepower hour	do	7.05
Dry coal:		
Per indicated horsepower hour	do	4.88
Per electrical horsepower hour	do	6.03

BRIQUETTING TEST.

Illinois No. 7 E (slack).

Test 244†.—Size as used: Over ¼ inch, 1.5 per cent; $\frac{1}{16}$ inch to ¼ inch, 6.6 per cent; $\frac{1}{32}$ inch to $\frac{1}{16}$ inch, 14.2 per cent; $\frac{1}{64}$ inch to $\frac{1}{32}$ inch, 22.0 per cent; through $\frac{1}{64}$ inch, 55.7 per cent. Briquets with 8 per cent binder were satisfactory, were easily handled from the machine without breaking, and became very hard when cold; fracture was rough and edges easily crumbled, owing to excessive amount of clay present; outer surfaces smooth, with dull color. For analyses of briquets see top of this page.

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held per cent	63.5
Temperature of briquets °F	167	Passed do	36.5
Binder		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held do	87.5
Laboratory No. (see p. 40)	4806	Passed (fines) do	12.5
Amount per cent	8	Fines through 10-mesh sieve do	97.2
Weight of—		Water absorption:	
Fuel briquetted pounds	12,000	In 10 days do	7.4
Briquets, average do	0.472	Average for first 3 days do	1.9
Heat value per pound—		Specific gravity (apparent)	1.257
Fuel as received B. t. u.	8,797		
Fuel as fired do	16,021		
Binder do	16,864		

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 244†.
Laboratory No	4806	4760	4928
Air-drying loss ... per cent	.....	10.60	1.70
Extracted by CS_2:			
Air dried ... do	.....	.47	8.24
As received ... do	96.90	.42	8.09
Pitch in briquets, as received ... do	.....	.....	7.96

ILLINOIS NO. 9.[a]

Bituminous slack coal from a mine near Staunton was designated Illinois No. 9 C. One carload, shipped uninspected, was used in steaming tests (on briquets) 492 and 497 and briquetting tests 189, 190, 233, and 234†.

CHEMICAL ANALYSES.

Illinois No. 9 C.

	Car sample.	Steaming tests.[a] 492.	Steaming tests.[a] 497.	Briquetting test 234†.[b]
Laboratory No	4247	4406	4473	4874
Air-drying loss	13.30	.....	15.10	3.10
Proximate:				
Moisture	15.25	14.62	17.43	5.43
Volatile matter	28.57	32.38	28.98	33.55
Fixed carbon	40.83	39.13	39.99	47.63
Ash	15.35	13.87	13.60	13.39
Sulphur	3.81	3.51	3.30	3.52
Ultimate:				
Hydrogen	5.22	4.33	4.31	4.44
Carbon	53.95	65.67	66.29	68.44
Nitrogen	.82	.88	.99	.94
Oxygen	20.85	8.77	7.94	8.30
Ash	.....	16.24	16.47	14.16
Sulphur	.....	4.11	4.00	3.72
Calorific value (as received):				
Determined ... calories	5,439	.....	5,524	6,507
Determined ... B. t. u.	9,790	.....	9,943	11,713
Calculated from ultimate analysis ... calories	5,344	.....	.....	.....
Calculated from ultimate analysis ... B. t. u.	9,619	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Illinois No. 9 C (English briquets).

	Test 492.	Test 497.
Duration of test ... hours	10.00	9.38
Heating value of fuel ... B. t. u. per pound dry fuel	12,037	12,042
Force of draft:		
Under stack damper ... inch water	0.91	0.84
Above fire ... do	.05	.18
In ash pit ... do	.16	.....
Furnace temperature ... °F	.....	2,605
Dry fuel used per square foot of grate surface per hour ... pounds	22.52	19.75
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.50	3.06
Percentage of rated horsepower of boiler developed	98.2	85.9
Water apparently evaporated per pound of fuel as fired ... pounds	5.51	5.32
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ... do	6.65	6.42
Per pound of dry fuel ... do	7.79	7.77
Per pound of combustible ... do	9.37	9.49
Efficiency of boiler, including grate (item 73) ... per cent	62.50	62.31
Fuel as fired:		
Per indicated horsepower hour ... pounds	4.25	4.40
Per electrical horsepower hour ... do	5.25	5.44
Dry fuel:		
Per indicated horsepower hour ... do	3.63	3.64
Per electrical horsepower hour ... do	4.48	4.49

[a] For other tests of coal from this mine (Illinois No. 9 A and Illinois No. 9 B), made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 63-66.

Remarks.—Forced draft was used in test 492 (on English briquets made in test 189) and natural draft in test 497 (briquetting test 190). Briquets were burned whole in both tests, but did not burn well with natural draft; 4.3 per cent black smoke. Test 492 made 51 per cent clinker; test 497 made 36 per cent clinker.

BRIQUETTING TESTS.

Illinois No. 9 C (slack).

Tests 189, 190, 233, 234.—Size as used: Over ¼ inch, 0.4 per cent; $\frac{1}{10}$ inch to ¼ inch, 3.9 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 14.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 25.1 per cent; through $\frac{1}{40}$ inch, 56.2 per cent. Briquets with 6 and 7 per cent binder were satisfactory, having hard surface but rough fracture without crumbling; outer surface of Renfrow briquets soft, although they stood handling from machine; fracture crumbly but briquets tough. This coal requires high pressure to make good briquets. For analyses of briquets see page 81 (briquets from test 189 under "Steaming test 492," from test 190 under "Steaming test 497").

	Test 189.	Test 190.	Test 233.	Test 234†.
Details of manufacture:				
Machine used	Eng.	Eng.	Renf.	Renf.
Temperature of briquets ... °F.	167	167	149	149
Binder—				
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4543	4543	4806	4806
Amount ... per cent	6	7	8	9
Weight of—				
Fuel briquetted ... pounds	12,000	12,000	18,000	5,000
Briquets, average ... do	3.85	3.73	0.448	0.426
Heat value per pound—				
Fuel as received ... B. t. u.	9,790	9,790	9,790	9,790
Fuel as fired ... do	10,276	9,943	(a)	11,713
Binder ... do	16,969	16,969	16,864	16,864
Drop test (1-inch screen):				
Held ... per cent	62.0	57.0	54.5	64.5
Passed ... do	38.0	43.0	45.5	35.5
Tumbler test (1-inch screen):				
Held ... do	77.2	76.2	87.5	88.5
Passed (fines) ... do	22.8	23.8	12.5	11.5
Fines through 10-mesh sieve ... do	80.3	81.4	95.5	84.6
Weathering test:				
Time exposed ... days	6	6	.....	.....
Condition	B	B	.....	.....
Water absorption:				
In 19 days ... per cent	9.4	12.0	.....	.....
In 13 days ... do	.....	.....	10.2	9.1
Average for first 3 days ... do	1.67	2.03	2.43	2.17
Specific gravity (apparent)	1.146	1.124	1.098	1.128

a No test.

Extraction analyses.

	Pitches.		Fuel.	Briquets.		
				Test 189.	Test 190.	Test 234†.
Laboratory No.	4543	4806	4247	4406	4473	4874
Air-drying loss ... per cent	.....	.....	13.50	12.30	15.10	3.10
Extracted by CS_2:						
Air-dried ... do	.....	.....	.73	7.18	7.28	9.71
As received ... do	99.66	96.90	.63	6.30	6.18	9.41
Pitch in briquets, as received ... do	.....	.....	.....	5.75	5.50	9.12

ILLINOIS NO. 12.[a]

Bituminous coal from Bush, Williamson County, designated Illinois No. 12 B, was No. 5 washed, and this sample was shipped uninspected and used washed in steaming test 463 (on briquets) and briquetting tests 166*, 177*†, and 181*.

CHEMICAL ANALYSES.

Illinois No. 12 B.

	Car samples, washed.			Steaming test 463.[a]	Briquetting tests.[b]	
					177*†.	181*.
Laboratory No	4201	3907	4085	4228		
Air-drying loss	13.30	9.00	12.40			
Proximate:						
Moisture	15.87	12.61	15.31	6.99	5.57	5.78
Volatile matter	28.19	30.08	28.93	32.36	32.38	32.62
Fixed carbon	46.42	46.81	45.29	50.24	50.96	49.80
Ash	9.52	10.50	10.47	10.41	11.09	11.80
Sulphur	2.34	2.37	2.32	2.41	2.41	2.58
Ultimate:						
Hydrogen	5.60	5.37	5.61	4.49	4.20	4.59
Carbon	59.66	62.15	59.88	72.03	70.09	71.48
Nitrogen	1.06	.93	1.04	1.09	1.11	1.09
Oxygen	21.82	18.68	20.68	8.61	10.28	7.57
Ash				11.19	11.77	12.53
Sulphur				2.59	2.55	2.74
Calorific value (as received):						
Determined, calories	5,991	6,148	6,011			
Determined, B. t. u.	10,784	11,066	10,820			
Calculated from ultimate analysis, calories	5,862	6,119	5,932			
Calculated from ultimate analysis, B. t. u.	10,552	11,014	10,693			

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TEST.

Illinois No. 12 B (Renfrow briquets.)

		Test 463.
Duration of test	hours	10.03
Heating value of fuel	B. t. u. per pound dry fuel	12,859
Force of draft with reference to atmospheric pressure:		
Under stack damper	inch water	0.81
Above fire	do	.11
Furnace temperature	°F	2,490
Dry fuel used per square foot of grate surface per hour	pounds	18.67
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.20
Percentage of rated horsepower of boiler developed		89.7
Water apparently evaporated per pound of fuel as fired	pounds	6.61
Water evaporated from and at 212 °F:		
Per pound of fuel as fired	do	7.98
Per pound of dry fuel	do	8.58
Per pound of combustible	do	9.84
Efficiency of boiler, including grate	per cent	64.44
Fuel as fired:		
Per indicated horsepower hour	pounds	3.54
Per electrical horsepower hour	do	4.37
Dry fuel:		
Per indicated horsepower hour	do	3.30
Per electrical horsepower hour	do	4.07

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 74-76.

Remarks.—Test 463 made on briquets from test 166*. Burned slowly with short flame and hot bed; 5 per cent black smoke; 41 per cent clinker, dark-gray color, stuck to grate. Ash contained fine unburned coal due to breaking up of fuel during combustion.

BRIQUETTING TESTS.

Illinois No. 12 B (washed).

Tests 166, 177*†, 181**.—Size as shipped: No. 5. Size as used: Over $\frac{1}{4}$ inch, 0.2 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 3.4 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 15.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 24.4 per cent; through $\frac{1}{40}$ inch, 56.8 per cent. For analyses of briquets see page 83. Analysis of briquets from test 166* given under "Steaming test 463." Excellent English briquets made with 6.25 per cent binder and Renfrow briquets with 7 per cent binder. Briquets easily handled when warm, although some difficulty was experienced in piling Renfrow briquets, which stuck together owing to low melting point of binder. Surfaces of all briquets were hard and smooth, with rough, clean fracture and sharp edges.

	Test 166*.	Test 177*†.	Test 181*.
Details of manufacture:			
Machine used	Renf.	Eng.	Renf.
Temperature of briquets ° F.	131	185	131
Binder—			
Kind	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4120	4543	4543
Amount per cent	8	0.25	7
Weight of—			
Fuel briquetted pounds	100,000	51,000	53,000
Briquets, average do	0.463	3.66	0.432
Heat value per pound—			
Fuel as received B. t. u.	10,784	10,784	10,784
Fuel as fired do	11,961	12,155	12,076
Binder do	17,060	16,969	16,969
Drop test (1-inch screen):			
Held per cent	66.5	85.1	65.5
Passed do	33.3	14.9	34.5
Tumbler test (1-inch screen):			
Held do	83.5	84.5	84.0
Passed (fines) do	16.5	15.5	16.0
Fines through 10-mesh sieve do	96.5	78.3	96.0
Weathering test:			
Time exposed days	63	12	19
Condition	B.	A.	B.
Water absorption:			
In 19 days per cent	13.3	8.5	15.0
Average for first 4 days do	2.15	1.00	2.13
Specific gravity (apparent)	1.074	1.101	1.041

Extraction analyses.

	Pitches.		Fuel.	Briquets.		
				Test 166*.	Test 177*†.	Test 181*.
Laboratory No.	4120	4543	4201	4228	.....	.....
Air-drying loss per cent	.....	.....	13.30	4.10	.....	.....
Extracted by CS_2:						
Air dried do	.....	.....	.....	6.54	.....	.....
As received do	97.70	99.66	.02	6.27	6.35	6.05
Pitch in briquets, as received do	.....	.....	.....	6.40	6.35	6.05

ILLINOIS NO. 19.[a]

Bituminous coal from bed No. 7 at Zeigler, Franklin County, was designated Illinois No. 19. The coal, as worked at a depth of 420 feet at this place, averages 6 feet 9 inches in thickness.

Three samples were shipped under the supervision of John W. Groves, as follows: Illinois No. 19 C consisted of run-of-mine coal, and was used in steaming tests 420 and 423 and producer-gas tests 128. Illinois No. 19 D consisted of lump coal over a 6-inch shaking screen and was used in steaming tests 424 and 425. Illinois No. 19 E consisted of screenings through a 1½-inch shaking screen and was used in steaming tests 421 and 422.

One mine sample (No. 3408) was taken for chemical analysis 1,500 feet southwest of the shaft, where the coal measured 11 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 19.

	Mine sample.	Steaming tests.[a]					
		C.		D.		E.	
		420.	423.	424.	425.	421.	422.
Laboratory No.	3408	.....	.....	.....	.....	.....	.....
Proximate:							
Moisture	9.65	8.72	9.42	8.45	8.51	9.22	9.75
Volatile matter	30.87	28.41	28.05	29.65	30.27	29.28	28.45
Fixed carbon	53.23	50.58	50.72	50.24	49.85	50.25	50.67
Ash	6.25	12.29	11.81	11.66	11.37	11.25	11.13
Sulphur	.45	.63	.61	.53	.51	.59	.61
Ultimate:							
Hydrogen	.....	4.64	4.67	4.12	4.13	4.13	4.13
Carbon	.....	71.08	71.44	70.23	70.51	70.47	71.48
Nitrogen	.....	1.56	1.57	1.59	1.60	1.60	1.58
Oxygen	.....	8.57	8.61	10.74	10.77	10.76	9.80
Ash	.....	13.46	13.04	12.74	12.43	12.39	12.33
Sulphur	.....	.69	.67	.58	.56	.65	.68

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 19.

	C.		D.		E.	
	Test 420.	Test 423.	Test 424.	Test 425.	Test 421.	Test 422.
Size as shipped	r. o. m.	r. o. m.	No. 6 lump.	No. 6 lump.	No. 2 nut.	No. 2 nut.
Size as used:						
Over 1 inch ... per cent	20.2	15.8	23.9	37.9	18.0	14.4
½ inch to 1 inch ... do	24.2	19.5	24.5	27.4	45.9	44.0
¼ inch to ½ inch ... do	19.1	18.3	18.7	15.0	16.6	17.8
Under ¼ inch ... do	36.5	46.4	32.9	19.7	19.5	23.8
Average diameter ... inch	0.66	0.57	0.71	0.91	0.78	0.72
Duration of test ... hours	10.03	10.03	10.0	10.00	10.0	10.07
Heating value of coal, B. t. u. per pound dry coal	12,431	12,496	12,416	12,460	12,454	12,578
Force of draft:						
Under stack damper ... inch water	0.65	0.59	0.64	0.65	0.66	0.62
Above fire ... do	.12	.14	.12	.14	.11	.12

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 91-94.

STEAMING TESTS—Continued.

Illinois No. 19.

	C.		D.		E.	
	Test 420.	Test 423.	Test 424.	Test 425.	Test 421.	Test 422.
Dry coal used per square foot of grate surface per hour ....pounds....	19.95	16.94	18.67	19.33	19.46	19.46
Equivalent water evaporated per square foot of water-heating surface per hour, pounds....	3.35	2.89	3.18	3.32	3.30	3.39
Percentage of rated horsepower of boiler developed....	93.9	81.0	89.1	93.0	92.5	95.0
Water apparently evaporated per pound of coal as fired....pounds..	6.61	6.66	6.73	6.79	6.63	6.78
Water evaporated from and at 212° F.:						
Per pound of coal as fired...pounds..	7.67	7.73	7.81	7.87	7.70	7.88
Per pound of dry coal.....do....	8.40	8.53	8.53	8.61	8.48	8.73
Per pound of combustible.....do....	10.00	10.12	10.00	10.09	9.93	10.20
Efficiency of boiler, including grate, per cent....	65.26	65.92	66.35	66.73	65.76	67.03
Coal as fired:						
Per indicated horsepower hour, pounds....	3.69	3.66	3.62	3.59	3.67	3.59
Per electrical horsepower hour, pounds....	4.55	4.52	4.47	4.44	4.53	4.43
Dry coal:						
Per indicated horsepower hour, pounds....	3.37	3.32	3.32	3.28	3.33	3.24
Per electrical horsepower hour, pounds....	4.16	4.09	4.09	4.05	4.12	4.00

PRODUCER-GAS TEST.

Illinois No. 19 C (run of mine).

Test 128.—Duration of test, 50 hours; average electrical horsepower, 141.0; average B. t. u. per cubic foot of gas, 137.8; total coal fired, 14,400 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available....	2.20	1.98	1.76
Developed at switchboard....	2.04	1.84	1.64
Per brake horsepower:			
Commercially available....	1.87	1.68	1.49
Developed at engine....	1.74	1.57	1.39
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available....	2.40	2.16	1.92
Developed at switchboard....	2.23	2.01	1.78
Per brake horsepower:			
Commercially available....	2.04	1.84	1.63
Developed at engine....	1.90	1.71	1.52

Analyses.

Coal.		*Gas by volume.*	
Moisture....	9.82	Carbon dioxide (CO_2)....	11.6
Volatile matter....	29.64	Carbon monoxide (CO)....	16.8
Fixed carbon....	50.34	Hydrogen (H_2)....	16.5
Ash....	10.20	Methane (CH_4)....	1.9
Sulphur....	.49	Nitrogen (N_2)....	52.9
		Ethylene (C_2H_4)....	.3

ILLINOIS NO. 20.

Bituminous coal from Staunton, Macoupin County, on the Litchfield and Madison Railroad, was designated Illinois No. 20.

This sample consisted of screenings, and was shipped by the operator, primarily for washing tests. It was used in steaming tests (washed coal) 292, 301, and 302; washing test 142; coking tests 106 (raw) and 107 (washed); and mixed with Kentucky No. 2 B (coke breeze, see p. 159) in briquetting tests 103 and 104.

CHEMICAL ANALYSES.

Illinois No. 20.

	Car sample.	Steaming tests.[a]		
		292.	301.	302.
Laboratory No.	2731			
Air-drying loss	12.40			
Proximate:				
Moisture	14.68	14.52	16.51	16.36
Volatile matter	31.32	31.98	32.17	33.54
Fixed carbon	40.32	38.01	40.87	39.84
Ash	13.68	15.49	10.45	10.26
Sulphur	3.88	4.32	3.25	3.22
Ultimate:				
Hydrogen	5.41	4.28	4.66	4.68
Carbon	55.21	62.59	68.11	68.34
Nitrogen	1.00	1.14	1.23	1.23
Oxygen	20.82	8.82	9.60	9.63
Ash		18.12	12.51	12.27
Sulphur		5.05	3.89	3.85
Calorific value (as received):				
Determined, calories	5,585			
Determined, B. t. u.	10,053			
Calculated from ultimate analysis, calories	5,517			
Calculated from ultimate analysis, B. t. u.	9,931			

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 20 (washed screenings).

	Test 292.	Test 301.	Test 302.
Size as used:			
Over 1 inch ... per cent	20.1	17.1	22.5
½ inch to 1 inch ... do	22.9	27.7	28.1
¼ inch to ½ inch ... do	18.7	23.7	21.9
Under ¼ inch ... do	38.3	31.5	27.5
Duration of test ... hours	9.8	9.95	9.02
Kind of grate		Rocking.	Rocking.
Heating value of coal ... B. t. u. per pound dry coal	11,425	12,506	12,548
Force of draft:			
Under stack damper ... inch water	0.53	0.57	0.53
Above fire ... do	.10	.30	.17
Furnace temperature ... °F	2,020		2,708
Dry coal used per square foot of grate surface per hour ... pounds	15.49	24.61	25.69
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	2.37	3.54	3.81
Percentage of rated horsepower of boiler developed	66.3	99.3	106.7
Water apparently evaporated per pound of coal as fired ... pounds	5.47	5.57	5.74
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	6.55	6.71	6.91
Per pound of dry coal ... do	7.66	8.04	8.27
Per pound of combustible ... do	9.61	9.43	9.57
Efficiency of boiler, including grate ... per cent	64.75	62.08	63.65
Coal as fired:			
Per indicated horsepower hour ... pounds	4.32	4.22	4.09
Per electrical horsepower hour ... do	5.33	5.20	5.05
Dry coal:			
Per indicated horsepower hour ... do	3.69	3.52	3.42
Per electrical horsepower hour ... do	4.56	4.34	4.22

WASHING AND COKING TESTS.

Illinois No. 20 (screenings).

Washing test 142.—Jig used, Stewart. Raw coal, 63,280 pounds; washed, 57,000 pounds; refuse, 6,280 pounds.

Coking tests.

		Test 106 (raw).	Test 107 (w.)
Size as used		f. c.	f. c.
Duration of test	hours	47	36
Coal charged	pounds	10,000	10,000
Coke produced	do	4,255	4,659
	per cent	42.55	46.59
Breeze produced	pounds	628	398
	per cent	6.28	3.98
Total yield	do	48.83	50.57

Remarks.—Test 106: Dull-gray color; dense; cross fracture of coke bad; ash and sulphur very high. Test 107: Dull-gray color; a little deposited carbon; ash and sulphur not materially reduced by washing; physically better than coke from raw coal; percentage of breeze shows large reduction.

Analyses.

	Washing test 142.		Coking test 106.		Coking test 107.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	14.68	16.80	17.04	0.57	14.36	0.53
Volatile matter	31.32	.....	32.59	.66	34.61	.29
Fixed carbon	40.32	.....	40.77	82.49	42.63	84.87
Ash	13.68	10.26	9.60	16.28	8.40	14.31
Sulphur	3.88	3.21	3.23	3.01	3.23	2.73

BRIQUETTING TESTS.

Illinois No. 20 mixed with Kentucky No. 2 B.

Tests 103, 104.—Size as shipped, breeze through 1-inch coke fork and coal screenings. Machine used, English. Temperature of briquets, 179.6° F. Kind of binder, coal-tar pitch. Amount of binder, 6 per cent. The flowing point of the binder used (laboratory No. 2729) was 255° F., and 61.2 per cent of the sample as received was extracted by CS_2. All other data concerning this binder were lost in the fire. Weight of fuel briquetted, 2,000 pounds.

Briquets made from coke breeze with 20 per cent, 33⅓ per cent, and 47 per cent coal, using 6 per cent pitch, were easily broken in handling; coke breeze was washed, one-half used wet and one-half put through drier. Briquets made with dried fuel handled better when hot, but there was no difference in the two briquets when cold. Washed breeze was too high in ash for satisfactory fuel.

These briquets were used in a preliminary test in switching locomotives. Briquets with 20 per cent coal burned too slowly for switching service. Briquets with 33⅓ per cent coal were satisfactory for switching, but burned too slowly for freight or passenger service. Briquets with 47 per cent coal were satisfactory for all services.

ILLINOIS NO. 21.

Bituminous coal from Troy, Madison County, on the St. Louis, Troy and Eastern Railroad, was designated Illinois No. 21. The coal as worked at a depth of 275 feet at this place averages 5 feet in thickness.

This sample which was taken under the inspection of John W. Groves, consisted of lump coal over a 2¼-inch screen. Five 40-ton cars were shipped to the testing plant, three of which were sent for an endurance test on the producer and the other two for a complete series of tests, as follows: Steaming tests 315 and 316 (washed coal) and 318 (on briquets), producer-gas test 105, washing test 160, coking tests 126 and 137 (washed coal), and briquetting test 113.

Two mine samples were taken for chemical analysis. Sample 2771 was cut 800 feet northwest of the bottom of the shaft, where the coal measured 5 feet 8 inches in thickness. Sample 2770 was cut 1,500 feet southeast of the bottom of the shaft, where the coal measured 4 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 21.

	Mine samples.		Car samples.		Steaming tests.[a]		
					315.	316.	318.
Laboratory No	2770	2771	2852	2920			
Air-drying loss	10.50	13.30	10.40	8.20			
Proximate:							
Moisture	15.23	17.79	15.54	15.30	14.95	15.07	17.31
Volatile matter	31.42	28.78	31.26	30.59	30.33	30.78	30.40
Fixed carbon	44.32	42.34	42.27	43.40	40.96	41.90	42.28
Ash	9.03	11.09	10.93	10.71	13.76	12.25	10.01
Sulphur	1.59	1.40	1.38	1.43	1.60	1.27	1.28
Ultimate:							
Hydrogen			5.59		4.39	4.50	4.41
Carbon			58.02		65.89	67.62	70.01
Nitrogen			1.09		1.23	1.27	1.32
Oxygen			22.99		10.43	10.69	10.61
Ash					16.18	14.42	12.10
Sulphur					1.88	1.50	1.55
Calorific value (as received):							
Determined, calories	6,056		5,837				
Determined, B. t. u.	10,901		10,507				
Calculated from ultimate analysis, calories			5,655				
Calculated from ultimate analysis, B. t. u.			10,179				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 21 (lump).

		Test 315.	Test 316.	Test 318.
Size as used:				
Over 1 inch	per cent	34.0	33.6	(a)
½ inch to 1 inch	do	21.3	20.6	
¼ inch to ½ inch	do	18.1	16.2	
Under ¼ inch	do	26.6	29.6	

[a] On briquets which were broken in two. The fuel cracked to center into coke fragments and held together until consumed. Percentage of clinker large.

STEAMING TESTS—Continued.

Illinois No. 21 (lump).

	Test 315.	Test 316.	Test 318.
Duration of test ..... hours	[a] 4.88	10.03	7.3
Heating value of fuel ..... B. t. u. per pound dry fuel	11,945	12,240	12,469
Force of draft:			
Under stack damper ..... inch water	0.63	0.59	0.76
Above fire ..... do	.16	.15	.04
Furnace temperature ..... °F	2,499	2,401	2,508
Dry fuel used per square foot of grate surface per hour ..... pounds	20.05	20.05	25.30
Equivalent water evaporated per square foot of water-heating surface per hour ..... pounds	3.27	3.19	4.11
Percentage of rated horsepower of boiler developed	91.6	89.3	115.3
Water apparently evaporated per pound of fuel as fired ..... pounds	5.76	5.67	5.6
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ..... do	6.94	6.76	6.73
Per pound of dry fuel ..... do	8.16	7.96	8.14
Per pound of combustible ..... do	9.95	9.53	9.40
Efficiency of boiler, including grate ..... per cent	65.97	62.80	63.04
Fuel as fired:			
Per indicated horsepower hour ..... pounds	4.07	4.18	4.20
Per electrical horsepower hour ..... do	5.03	5.16	5.19
Dry coal:			
Per indicated horsepower hour ..... do	3.46	3.55	3.47
Per electrical horsepower hour ..... do	4.28	4.39	4.29

[a] Too short for reliable results.

PRODUCER-GAS TEST.

Illinois No. 21 (lump).

Test 105.—Duration of test,[a] 562 hours; average electrical horsepower, 191.7; average B. t. u. per cubic foot of gas, 156.1; total coal fired, 208,350 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.04	1.74	1.50
Developed at switchboard	1.93	1.65	1.43
Per brake horsepower:			
Commercially available	1.73	1.47	1.28
Developed at engine	1.64	1.40	1.22
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.18	1.86	1.61
Developed at switchboard	2.07	1.77	1.53
Per brake horsepower:			
Commercially available	1.85	1.58	1.37
Developed at engine	1.76	1.50	1.30

Analyses.

Coal.		*Gas by volume.*	
Moisture	14.68	Carbon dioxide (CO_2)	9.2
Volatile matter	30.98	Carbon monoxide (CO)	20.9
Fixed carbon	42.93	Hydrogen (H_2)	15.6
Ash	11.41	Methane (CH_4)	1.9
Sulphur	1.33	Nitrogen (N_2)	52.0
		Ethylene (C_2H_4)	.4

[a] See p. 26.

WASHING AND COKING TESTS.

Illinois No. 21 (lump).

Washing test 160.—Size as used, crushed to 2 inches. Jig used, Stewart. Raw coal, 17,000 pounds; washed, 14,640 pounds; refuse, 2,360 pounds.

Coking tests.

	Test 126 (raw).	Test 137 (washed).
Size as used	f. c.	f. c.
Duration of test ... hours	44	45
Coal charged ... pounds	12,000	11,690
Coke produced	None.	None.

Remarks.—Test 137: Product a mixture of unburned coal and slightly coherent mass of coal of original size, showing no trace of cell structure. All volatile expelled.

Analyses.

	Washing test 160.		Coking test 126 (coal).	Coking test 137 (coal).
	Raw coal.	Washed coal.		
Moisture	15.30	8.25	13.37	17.45
Volatile matter	30.59	.....	31.17	30.01
Fixed carbon	43.40	.....	43.15	44.74
Ash	10.71	8.09	12.31	7.80
Sulphur	1.43	1.25	1.46	1.10

BRIQUETTING TEST.

Illinois No. 21 (lump).

Test 113.—Machine used, English; temperature of briquets, 179.6° F.; kind of binder, coal-tar pitch; laboratory No. 2933 (see p. 40); amount of binder, 5 and 6 per cent; weight of fuel briquetted, 14,000 pounds. B. t. u. per pound of coal as received, 12,440; per pound of briquets as fired, 12,469; per pound of binder, 15,937. Briquets made with 5 per cent binder were hard and firm, and stood rough handling. Weathering test: Days' exposure, 75; condition of briquets made with 5 per cent binder, B.

ILLINOIS NO. 22.

Bituminous coal from Maryville, Madison County, on the St. Louis, Troy and Eastern Railroad, was designated Illinois No. 22. The coal, as worked at a depth of 260 feet at this place, averages 7 feet 6 inches in thickness.

Two lots of coal were shipped from this locality under the supervision of John W. Groves. The first lot, Illinois No. 22 A, consisted of lump coal over a 4-inch perforated shaker screen. It was used in making steaming tests 324 (raw), 325 (raw), and 328 (washed); producer-gas test 102; and washing test 151. The second lot, Illinois No. 22 B, consisted of nut, pea, and slack coal which was screened through a 2-inch perforated screen. It was used in making washing test 150; coking tests 117 (raw) and 118 (washed); and cupola test 125.

Two mine samples were taken for chemical analysis. Sample 2772 was cut 300 feet south of the bottom of the shaft, where the coal measured 8 feet 2 inches in thickness. Sample 2773 was taken 2,500 feet north of the bottom of the shaft, where the coal measured 7 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 22.

	Mine samples.		Car samples.		Steaming tests.[a]		
			A.	B.	324.	325.	328.
Laboratory No	2772	2773	2905	2896			
Air-drying loss	9.20	9.90	5.90	11.20			
Proximate:							
Moisture	13.51	13.83	11.91	13.03	11.50	10.53	14.35
Volatile matter	34.64	34.16	35.65	32.65	33.44	35.63	36.86
Fixed carbon	41.70	42.24	39.43	39.79	39.27	40.04	40.57
Ash	10.15	9.77	13.01	14.53	15.79	13.80	8.22
Sulphur	4.01	4.10	5.34	4.35	6.24	6.07	3.75
Ultimate:							
Hydrogen			5.21	5.25	4.18	4.33	4.79
Carbon			57.35	55.94	61.77	63.97	70.73
Nitrogen			1.00	.89	1.07	1.12	1.23
Oxygen			18.09	19.04	8.09	8.37	9.27
Ash					17.84	15.43	9.60
Sulphur					7.05	6.78	4.38
Calorific value (as received):							
Determined, calories	6,045		5,897	5,662			
Determined, B. t. u.	10,881		10,615	10,192			
Calculated from ultimate analysis, calories			5,771	5,607			
Calculated from ultimate analysis, B. t. u.			10,388	10,093			

[a] Proximate analysis of fuel as fired: ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 22 A (lump).

	Test 324 (raw).	Test 325 (raw).	Test 328 (washed)
Size as used:			
Over 1 inch ... per cent	84.6	87.4	34.1
½ inch to 1 inch ... do	5.8	5.4	27.0
¼ inch to ½ inch ... do	3.5	6.2	22.0
Under ¼ inch ... do	6.1	4.6	16.9
Average diameter ... inches	4	4	
Duration of test ... hours	9.93	10	9.9
Heating value of coal ... B. t. u. per pound dry coal	11,484	11,876	12,924
Force of draft:			
Under stack damper ... inch water	0.59	0.54	0.78
Above fire ... do	.20	.18	.14
Furnace temperature ... °F	2,850	2,828	2,829
Dry coal used per square foot of grate surface per hour ... pounds	23.08	22.61	26.73
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.60	3.60	4.34
Percentage of rated horsepower of boiler developed	100.9	101.0	121.8
Water apparently evaporated per pound of coal as fired ... pounds	5.78	5.92	5.78
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... pounds	6.91	7.14	6.97
Per pound of dry coal ... do	7.81	7.97	8.14
Per pound of combustible ... do	9.70	9.61	9.16
Efficiency of boiler, including grate ... per cent	65.67	64.81	60.82
Coal as fired:			
Per indicated horsepower hour ... pounds	4.09	3.96	4.06
Per electrical horsepower hour ... do	5.05	4.89	5.01
Dry coal:			
Per indicated horsepower hour ... do	3.62	3.55	3.47
Per electrical horsepower hour ... do	4.47	4.38	4.29

PRODUCER-GAS TEST.

Illinois No. 22 A (lump).

Test 102.—Duration of test, 47 hours; average electrical horsepower, 196.5; average B. t. u. per cubic foot of gas, 159.6; total coal fired, 16,300 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.88	1.67	1.42
Developed at switchboard	1.77	1.57	1.33
Per brake horsepower:			
Commercially available	1.60	1.42	1.21
Developed at engine	1.50	1.33	1.13
Equivalent used by producer plant.			
Per electrical horsepower:			
Commercially available	2.09	1.77	1.51
Developed at switchboard	1.88	1.66	1.42
Per brake horsepower			
Commercially available	1.70	1.51	1.28
Developed at engine	1.59	1.41	1.20

Analyses.

Coal.		*Gas by volume.*	
Moisture	11.29	Carbon dioxide (CO_2)	9.4
Volatile matter	35.60	Carbon monoxide (CO)	20.2
Fixed carbon	39.94	Hydrogen (H_2)	13.7
Ash	13.17	Methane (CH_4)	2.0
Sulphur	4.88	Nitrogen (N_4)	54.0
		Ethylene (C_2H_4)	.7

WASHING AND COKING TESTS.

Illinois No. 22.

Washing tests.

	Test 151 (A).	Test 150 (B).		Test 151 (A).	Test 150 (B).
Size as shipped	1.	sc.	Raw coal ....pounds..	19,400	40,000
Size as used	cr. to 2"	sc.	Washed coal ....do....	17,000	22,000
Jig used	Stewart.	Stewart.	Refuse ....do....	2,400	8,000

Coking tests (B).

		Test 117 (raw).	Test 118 (washed).
Size as shipped		sc.	sc.
Size as used		f. c.	f. c.
Duration of test	hours..	45	76
Coal charged	pounds..	10,000	12,000
Coke produced	....do....	5,046	5,616
	per cent..	50.46	46.80
Breeze produced	pounds...	534	574
	per cent..	5.34	4.78
Total yield	....do....	55.80	51.58

Remarks.—Test 117: Dull-gray color; breakage very irregular, due to high percentage of slate; ash and sulphur high; poor coke. Test 118: Light-gray color, with heavy black butt due to necessity of closing draft after 24 hours. Charge held in oven 148 hours. Ash reduced by washing. Will probably make fair coke under proper conditions.

Analyses.

	Washing test 151 (A).		Washing test 150 (B).		Coking test 117 (B).		Coking test 118 (B).	
	Raw coal.	Washed coal.	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	11.91	14.02	13.03	16.78	11.98	0.98	16.19	0.65
Volatile matter	35.65	.....	32.65	.....	33.87	.72	34.14	1.60
Fixed carbon	39.43	.....	39.79	.....	37.72	72.18	39.53	80.76
Ash	13.01	8.58	14.53	9.99	16.43	26.12	10.14	16.99
Sulphur	5.34	3.69	4.35	3.79	4.74	4.61	3.79	3.65

Cupola test of coke made from Illinois No. 22 B coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
125	118	1.84	1 to 7	98.61	Coke	210	55	55	55	55	430
					Pig iron	630	405	405	405	405	2,250
					Scrap	210	135	135	135	135	750

[a] Sulphur in ash, 0.05 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
125	3.04 p. m.	7	8	1,191	325	1,516	34	2,675	3.92	6.80	1,280	43

LADLE RECORD.

Ladle No.	Test 125.		Ladle No.	Test 125.	
	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).
1	80	3.20	10	79	3.33
2	74	3.20½	11	60	3.38
3	96	3.23	12	68	3.38½
4	81	3.24	13	105	3.39
5	94	3.26	14	29	3.39½
6	62	3.26½	15	92	3.44
7	62	3.31	16	24	3.45
8	74	3.32	17	33	3.46
9	78	3.32½			

Remarks.—Test 125: Iron hot.

ILLINOIS NO. 23.

Bituminous coal from Donkville, Madison County, on the St. Louis, Troy and Eastern Railroad, was designated Illinois No. 23. The coal, as worked at a depth of 145 feet at this place, averages 6 feet in thickness.

This sample consisted of two lots of coal and was shipped under the supervision of John W. Groves. Illinois No. 23 A consisted of "superior lump" over a 5-inch perforated screen, and was used in steaming tests 306 (raw) and 317 (washed); producer-gas test 98;

washing test 146; and coking test 111. Illinois No. 23 B consisted of slack coal through a 2-inch perforated screen, and was used in steaming tests (on briquets) 321 and 322; producer-gas test 100; washing test 147; coking tests 112 and 114, both on washed coal; and briquetting test 116.

Two mine samples were taken for chemical analysis. Sample 2774 was cut 3,800 feet northeast of the shaft, where the coal measured 6 feet 1 inch in thickness. Sample 2775 was cut 4,000 feet northwest of the shaft, where the coal measured 6 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 23.

	Mine samples.		Car samples.		Steaming tests.[a]		
			A.	B.	306.	317.	321 and 322.
Laboratory No	2774	2775	2819	2803	.....	.....	.....
Air-drying loss	8.90	9.70	11.50	13.20	.....	.....	.....
Proximate:							
Moisture	13.07	12.79	13.47	15.68	14.49	14.64	13.54
Volatile matter	34.85	35.67	34.35	31.28	32.37	35.72	36.33
Fixed carbon	42.02	40.25	40.65	37.45	39.69	40.76	41.67
Ash	10.06	11.29	11.53	15.59	13.45	8.88	8.41
Sulphur	3.59	3.94	4.41	3.98	4.62	3.23	3.21
Ultimate:							
Hydrogen	.....	.....	5.63	5.42	4.62	5.03	4.86
Carbon	.....	.....	57.61	52.89	64.36	70.04	69.30
Nitrogen	.....	.....	.91	.90	1.02	1.10	1.14
Oxygen	.....	.....	19.91	21.22	8.87	9.65	11.26
Ash	.....	.....	.....	.....	15.73	10.40	9.73
Sulphur	.....	.....	.....	.....	5.40	3.78	3.71
Calorific value (as received):							
Determined: calories	6,083	.....	5,839	5,364	.....	.....	.....
Determined: B. t. u.	10,949	.....	10,510	9,655	.....	.....	.....
Calculated from ultimate analysis: calories	.....	.....	5,836	5,317	.....	.....	.....
Calculated from ultimate analysis: B. t. u.	.....	.....	10,505	9,571	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 23.

	A (lump).		B (slack).	
	Test 306.	Test 317 (w).	Test 321.	Test 322.
Size as used:				
Over 1 inch ... per cent	37.3	18.9	See p. 96	See p. 96.
½ inch to 1 inch ... do	19.5	26.7		
¼ inch to ½ inch ... do	16.2	24.3		
Under ¼ inch ... do	27.0	30.1		
Duration of test ... hours	9.4	8.12	4.4	3.65
Heating value of fuel ... B. t. u. per pound of dry fuel	11,759	12,794	12,996	12,996
Force of draft:				
Under stack damper ... inch water	0.46	0.55	0.75	0.65
Above fire ... do	.13	.13	.27	.16
Furnace temperature ... °F	2,402	2,397	.....	.....
Dry fuel used per square foot of grate surface per hour ... pounds	18.50	19.63	23.75	24.54
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.01	3.23	3.78	3.80
Percentage of rated horsepower of boiler developed	84.3	90.4	106.0	106.6
Water apparently evaporated per pound of fuel as fired, pounds	5.80	5.89	5.72	5.62
Water evaporated from and at 212° F.:				
Per pound of fuel as fired ... pounds	6.97	7.02	6.89	6.71
Per pound of dry fuel ... do	8.15	8.23	7.97	7.76
Per pound of combustible ... do	9.87	9.31	8.92	8.68
Efficiency of boiler, including grate ... per cent	66.93	62.12	59.22	57.66
Fuel as fired:				
Per indicated horsepower hour ... pounds	4.06	4.03	4.10	4.21
Per electrical horsepower hour ... do	5.01	4.97	5.07	5.20
Dry coal:				
Per indicated horsepower hour ... do	3.47	3.44	3.55	3.64
Per electrical horsepower hour ... do	4.29	4.24	4.38	4.50

. They burned
oke, coking and

S TESTS.

I . 23.

	Test 98 (A).	Test 100 (B, w.).
Size as shipped	5-inch lump.	s.
Size as used:		
Over 1 inch ... per cent	81	34
¼ inch to 1 inch ... do	3	24
⅛ inch to ¼ inch ... do	4	20
Under ⅛ inch ... do	12	22
Duration of test ... hours	50	50
Average electrical horsepower	198.3	181.5
Average B. t. u. per cubic foot of gas	147.9	145.0
Total coal fired ... pounds	18,000	17,250

	8.			Test 100.		
	Coal as fired.	Dry c al.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	1.91	1.69	1.46	2.00	1.70	1.52
Developed at switch board	1.82	1.60	1.38	1.90	1.62	1.45
Per brake horsepower:						
Commercially available	1.63	1.43	1.24	1.70	1.45	1.29
Developed at engine	1.54	1.36	1.18	1.62	1.38	1.23
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	2.02	1.78	1.54	2.17	1.85	1.66
Developed at switch board	1.91	1.69	1.46	2.07	1.76	1.57
Per brake horsepower:						
Commercially available	1.71	1.51	1.31	1.85	1.57	1.41
Developed at engine	1.63	1.43	1.24	1.76	1.50	1.34

Analyses.

	Test 98.	Test 100.		Test 98.	Test 100.
Coal.			*Gas by volume.*		
Moisture	11.87	14.77	Carbon dioxide (CO_2)	8.4	10.9
Volatile matter	36.37	35.23	Carbon monoxide (CO)	20.9	17.2
Fixed carbon	39.87	40.98	Hydrogen (H_2)	12.9	13.8
Ash	11.89	9.02	Methane (CH_4)	1.6	2.1
Sulphur	4.65	3.46	Nitrogen (N_2)	55.7	55.3
			Ethylene (C_2H_4)	.5	.7

WASHING AND COKING TESTS.

Illinois No. 23.

Washing tests.

	Test 146 (A).	Test 147 (B).		Test 146 (A).	Test 147 (B).
Size as shipped	5-inch lump.	s.	Jig used	Stewart.	Stewart.
			Raw coal ... pounds	28,000	80,000
Size as used	Crushed to 2-inch.	s.	Washed coal ... do	24,000	63,000
			Refuse ... do	4,000	17,000

Coking tests (on washed coal).

	A.	B.	
	Test 111.	Test 112.	Test 114.
Size as shipped	l.	s.	s.
Size as used	f. c.	f. c.	f. c.
Duration of test ... hours	39	43	72
Coal charged ... pounds	10,000	10,000	14,000
Coke produced ... do	4,211	4,407	6,443
Coke produced ... per cent	42.11	44.07	46.02
Breeze produced ... pounds	347	389	601
Breeze produced ... per cent	3.47	3.89	4.29
Total yield ... do	45.58	47.96	50.31

Remarks.—Tests 111 and 112: Good heavy coke; light gray and silvery; ash and sulphur high. Test 114: Light gray and silvery, not as good as coke from smaller charge (test 112); ash and sulphur high.

Analyses.

	Washing test 146 (A).		Washing test 147 (B).		Coking test 111 (A).		Coking test 112 (B).		Coking test 114 (B).	
	Raw coal.	Washed coal.	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	13.47	13.81	15.68	16.83	13.74	0.66	15.85	0.96	15.93	1.36
Volatile matter	34.35	.....	31.28	.....	36.47	0.74	35.02	1.14	35.88	1.19
Fixed carbon	40.65	.....	37.45	.....	41.01	83.45	40.57	82.66	40.16	82.83
Ash	11.53	8.78	15.59	8.75	8.78	15.15	8.56	15.24	8.03	14.62
Sulphur	4.41	3.54	3.98	3.22	3.57	3.09	3.27	2.87	3.25	2.84

BRIQUETTING TEST.

Illinois No. 23 B (slack).

Test 116.—Size as shipped, through 2½-inch round shaker screen. Machine used, English. Temperature of briquets, 179.6° F. Kind of binder, coal-tar pitch; laboratory No. 2933 (see p. 40). Amount of binder, 5, 6, and 6.5 per cent. Weight of coal briquetted, 12,000 pounds. B. t. u. per pound of coal as received, 11,450; per pound of briquets as fired, 12,996; per pound of binder, 15,937. For analyses of briquets see page 95 (steaming tests 321 and 322).

Briquets made with 5 and 6 per cent binder broke up in handling. Those made with 6.5 per cent were satisfactory. In the weathering test all binders were exposed seventy days; condition of the 5 per cent D, of the 6 per cent C, of the 6.5 per cent B.

ILLINOIS NO. 24.

Bituminous coal from New Baden, Clinton County, on the Southern Railway, was designated Illinois No. 24. The coal, as worked at a depth of 320 feet at this place, averages 7 feet 6 inches in thickness.

Two lots of coal were shipped under the supervision of W. J. Von Borries, as follows: Illinois No. 24 A consisted of screenings which had passed through a 2½-inch shaking screen, and was used in washing test 169 and coking tests 119 and 155. Illinois No. 24 B consisted of lump coal over a 5½-inch bar screen, and was used in steaming tests 335, 336, and 337; producer-gas test 103; washing test 166; and coking test 145.

Two mine samples were taken for chemical analysis. Sample 2854 was cut 400 feet northwest of the shaft, where the coal measured 7 feet 8 inches in thickness. Sample 2855 was cut 600 feet northeast of the shaft, where the coal measured 8 feet in thickness.

CHEMICAL ANALYSES.

Illinois No. 24.

	Mine samples.		Car B sample.[a]	Steaming tests.[b]		
				335.	336.	337.
Laboratory No.	2854	2855	2972			
Air-drying loss	10.10	9.60	7.40			
Proximate:						
Moisture	13.43	12.73	11.44	12.14	12.60	13.52
Volatile matter	33.02	33.35	33.93	33.71	34.40	32.84
Fixed carbon	44.37	44.32	43.92	42.48	43.13	43.17
Ash	9.18	9.60	10.71	11.67	9.87	10.47
Sulphur	3.35	3.60	4.94	4.53	3.83	3.97
Ultimate:						
Hydrogen			5.39	4.61	4.77	4.71
Carbon			60.06	67.18	69.47	68.61
Nitrogen			1.02	1.14	1.18	1.17
Oxygen			17.88	8.63	8.91	8.81
Ash				13.28	11.29	12.11
Sulphur				5.16	4.38	4.59
Calorific value (as received):						
Determined, calories	6,076		6,088			
Determined, B. t. u.	10,937		10,958			
Calculated from ultimate analysis, calories			6,049			
Calculated from ultimate analysis, B. t. u.			10,888			

[a] Sample from producer-gas test 103 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of fuel figured from car sample.

STEAMING TESTS.

Illinois No. 24 B (lump).

	Test 335.	Test 336.	Test 337.
Size as used:			
Over 2 inches ... per cent			92.0
Over 1 inch ... do	49.7	22.1	
½ inch to 1 inch ... do	19.9	25.2	3.2
¼ inch to ½ inch ... do	12.4	19.6	1.6
Under ¼ inch ... do	18.0	33.1	3.2
Duration of test ... hours	9.62	6.05	[a] 3.88
Heating value of coal ... B. t. u. per pound dry coal	12,245	12,623	12,474
Force of draft:			
Under stack damper ... inch water	0.55	0.63	0.61
Above fire ... do	.22	.26	.20
Furnace temperature ... °F	2,708		
Dry coal used per square foot of grate surface per hour ... pounds	20.49	21.48	23.63
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.30	3.29	3.82
Percentage of rated horsepower of boiler developed	92.6	92.3	107.0
Water apparently evaporated per pound of coal as fired ... pounds	5.90	5.59	5.84
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	7.09	6.71	7.00
Per pound of dry coal ... do	8.07	7.67	8.10
Per pound of combustible ... do	9.50	8.97	9.43
Efficiency of boiler, including grate ... per cent	63.64	58.68	62.71
Coal as fired:			
Per indicated horsepower hour ... pounds	3.99	4.21	4.04
Per electrical horsepower hour ... do	4.93	5.20	4.99
Dry coal:			
Per indicated horsepower hour ... do	3.50	3.69	3.49
Per electrical horsepower hour ... do	4.33	4.55	4.31

[a] Too short for reliable results.

PRODUCER-GAS TEST.

Illinois No. 24 B (lump).

Test 103.—Size as used: Over 1 inch, 63 per cent; ½ inch to 1 inch, 16 per cent; ¼ inch to ½ inch, 10 per cent; under ¼ inch, 11 per cent. Duration of test, 50 hours; average electrical horsepower, 200.4; average B. t. u. per cubic foot of gas, 160.5; total coal fired, 14,650 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.54	1.36	1.19
Developed at switch board	1.46	1.29	1.14
Per brake horsepower:			
Commercially available	1.31	1.16	1.02
Developed at engine	1.24	1.10	0.97
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.63	1.45	1.27
Developed at switch board	1.55	1.38	1.21
Per brake horsepower:			
Commercially available	1.39	1.23	1.08
Developed at engine	1.32	1.17	1.03

Analysis of gas, by volume.[a]

Carbon dioxide (CO_2)	8.4	Nitrogen (N_2)	52.5
Carbon monoxide (CO)	22.6	Oxygen (O_2)	.1
Hydrogen (H_2)	13.8	Ethylene (C_2H_4)	.5
Methane (CH_4)	2.1		

WASHING AND COKING TESTS.

Illinois No. 24.

Washing tests.

	Test 169 (A).	Test. 166 (B).			Test. 169 (A).	Test 166 (B).
Size as shipped	sc.	l.	Raw coal	pounds	20,000	18,745
Size as used	sc.	cr. to 2".	Washed coal	do	15,000	16,660
Jig used	Stewart.	Stewart.	Refuse	do	5,000	2,085

Coking tests.

		A.		B.
		Test 119 (raw).	Test 155 (w.).	Test 145 (w.).
Size as shipped		sc.	sc.	l.
Size as used		sc.	f. c.	f. c.
Duration of test	hours	24	78	55
Coal charged	pounds	10,000	11,410	11,830
Coke produced	do	None.	None.	4,710
	per cent			39.81
Breeze produced	pounds			1,350
	per cent			11.41
Total yield	do			51.22

Remarks.—Test 119: Ashed over whole oven about 4 inches down. Test 155: All volatile driven off. High heat of by-product ovens might coke. Test 145: Poor, soft, dense coke; sulphur high.

[a] For analysis of the fuel used see p. 98 (car sample 2972).

Analyses.

	Washing test 169 (A).		Washing test 166 (B, washed coal).	Coking test 119 (A coal).	Coking test 155 (A coal).	Coking test 145 (B).	
	Raw coal.[a]	washed coal.				Coal.	Coke.
Moisture	11.44	15.10	14.36	13.28	15.18	8.93	5.62
Volatile matter	33.93	.....	.....	29.93	32.13	35.22	1.64
Fixed carbon	43.92	.....	.....	39.03	43.46	46.29	79.01
Ash	10.71	9.75	8.38	17.76	9.23	9.56	13.73
Sulphur	4.94	3.18	3.31	4.05	3.07	3.41	2.97

[a] Sample from producer-gas test 103 (on B coal).

ILLINOIS NO. 25.

Bituminous coal from a mine located one-half mile east of Germantown, Clinton County, on the Southern Railway, was designated Illinois No. 25. The coal, as worked at a depth of 345 feet at this place, averages 4 feet 8 inches in thickness.

This sample was shipped under the supervision of John W. Groves. Two lots of coal, consisting of run of mine (designated A) and lump (designated B), the latter over a 1¾-inch screen, were shipped in the same car, and separated from each other by a partition. The following tests were made: On A and B mixed, steaming tests 338 and 339; on A, washing test 162 and coking tests 120 (raw) and 140 (washed), and on B, producer-gas test 104.

Two mine samples were taken for chemical analysis. Sample 2856 was cut 2,100 feet north of the shaft, where the coal measured 4 feet 10 inches in thickness. Sample 2857 was taken 2,200 feet northwest of the shaft, where the coal measured 4 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 25.

	Mine samples.		Car sample (B).[a]	Steaming tests.[b]	
				338.	339.
Laboratory No.	2856	2857	2991	.....	.....
Air-drying loss	6.70	7.60	5.90	.....	.....
Proximate:					
Moisture	11.64	12.15	11.35	12.28	11.53
Volatile matter	35.41	35.60	34.62	35.52	34.93
Fixed carbon	44.29	42.97	40.63	40.53	39.75
Ash	8.66	9.28	13.40	11.67	13.79
Sulphur	3.41	4.01	4.76	3.57	4.89
Ultimate:					
Hydrogen	.....	.....	5.41	4.87	4.65
Carbon	.....	.....	57.36	67.23	64.20
Nitrogen	.....	.....	1.05	1.23	1.18
Oxygen	.....	.....	18.02	9.30	8.85
Ash	.....	.....	.....	13.30	15.59
Sulphur	.....	.....	.....	4.07	5.53
Calorific value (as received):					
Determined, calories	6,272	.....	5,963	.....	.....
Determined, B. t. u.	11,290	.....	10,733	.....	.....
Calculated from ultimate analysis, calories	.....	.....	5,831	.....	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	10,496	.....	.....

[a] Sample from producer-gas test 104 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 25 (run of mine and lump mixed).

	Test 338.	Test 339.
Size as used:		
Over 3½ inches ... per cent	3.33	.....
3½ inches to 2¼ inches ... do	28.1	.....
3 inches ... do	.....	56.0
1½ inches to 1 inch ... do	.....	26.4
½ inch to 1 inch ... do	14.3	7.2
¼ inch to ½ inch ... do	9.1	4.0
Under ¼ inch ... do	15.2	6.4
Duration of test ... hours	9.67	10.0
Heating value of coal ... B. t. u. per pound dry coal	12,519	12,022
Force of draft:		
Under stack damper ... inch water	0.75	0.74
Above fire ... do	.21	.21
Dry coal used per square foot of grate surface per hour ... pounds	21.36	23.63
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.10	3.54
Percentage of rated horsepower of boiler developed	87.0	99.1
Water apparently evaporated per pound of coal as fired ... pounds	5.35	5.55
Water evaporated from and at 212° F.:		
Per pound of coal as fired ... do	6.38	6.63
Per pound of dry coal ... do	7.28	7.50
Per pound of combustible ... do	8.68	9.19
Efficiency of boiler, including grate ... per cent	56.16	60.25
Coal as fired:		
Per indicated horsepower hour ... pounds	4.43	4.26
Per electrical horsepower hour ... do	5.47	5.27
Dry coal:		
Per indicated horsepower hour ... do	3.88	3.77
Per electrical horsepower hour ... do	4.80	4.66

PRODUCER-GAS TEST.

Illinois No. 25 B (lump).

Test 104.—Duration of test, 50 hours; average electrical horsepower, 200.6; average B. t. u. per cubic foot of gas, 168.0; total coal fired, 16,000 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.68	1.49	1.27
Developed at switch board	1.60	1.41	1.20
Per brake horsepower:			
Commercially available	1.43	1.27	1.08
Developed at engine	1.36	1.20	1.02
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.78	1.58	1.34
Developed at switch board	1.68	1.49	1.27
Per brake horsepower:			
Commercially available	1.51	1.34	1.14
Developed at engine	1.43	1.27	1.08

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	8.3
Carbon monoxide (CO)	22.5
Hydrogen (H_2)	13.6
Mathane (CH_4)	2.2
Nitrogen (N_2)	52.9
Ethylene (C_2H_4)	.5

[a] For analysis of the fuel used, see p. 100 (car sample 2991).

WASHING AND COKING TESTS.

Illinois No. 25 A (run of mine).

Washing test 162.—Size as used, crushed to 2 inches. Jig used, Stewart. Raw coal, 14,550 pounds; washed, 12,000 pounds; refuse, 2,550 pounds.

Coking tests.

		Test 120 (raw).	Test 140 (w.).
Size as used		r. o. m.	f. c.
Duration of test	hours	79	62
Coal charged	pounds	10,000	11,830
Coke produced	do	None.	5,355
	per cent		45.27
Breeze produced	pounds		710
	per cent		6.00
Total yield	do		51.27

Remarks.—Test 140: Dull-gray color, cell structure close; soft, dense coke; breakage poor. Coked in two distinct layers of 16 inches and 8 inches, the lower coming out in chunks.

Analyses.

	Washing test 162 (washed coal).[a]	Coking test 120 (coal).	Coking test 140.	
			Coal.	Coke.
Moisture	14.14	12.96	13.40	2.71
Volatile matter		33.01	33.83	4.67
Fixed carbon		39.60	43.66	77.69
Ash	8.98	14.43	9.11	14.93
Sulphur	3.05	4.09	2.99	2.32

[a] For analysis of raw coal from this mine, see p. 100 (analysis 2991, of B (lump) coal).

ILLINOIS NO. 26.

Bituminous coal from Lincoln, Logan County, on the Chicago and Alton Railroad, was designated Illinois No. 26. The coal, as worked at a depth of 276 feet at this place, averages 4 feet 11 inches in thickness.

This sample was shipped under the supervision of John W. Groves. It consisted of run-of-mine coal and was used in making steaming tests 341 and 342, producer-gas test 126, washing test 164, and coking test 143 (on washed coal).

Two mine samples were taken for chemical analysis. Sample 2881 was taken 1,500 feet southeast of the shaft, where the coal measured 4 feet 11 inches in thickness. Sample 2882 was taken 1,600 feet northeast of the shaft, where the coal measured 4 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 26.

	Mine sample.		Car sample.	Steaming tests.[a]	
				341.	342.
Laboratory No	2881	2882	[b] 3003		
Air-drying loss	11.30	12.10	12.70		
Proximate:					
Moisture	14.77	15.52	15.68	13.55	15.68
Volatile matter	32.90	32.27	32.41	33.11	32.41
Fixed carbon	39.75	39.86	39.82	40.24	39.82
Ash	12.58	12.35	12.09	13.10	12.09
Sulphur	3.95	3.65	3.51	4.45	3.51
Ultimate:					
Hydrogen			5.56	4.43	4.53
Carbon			56.76	65.81	67.31
Nitrogen			1.06	1.23	1.26
Oxygen			21.02	8.23	8.40
Ash				15.15	14.34
Sulphur				5.15	4.16
Calorific value (as received):					
Determined, calories			5,675		
Determined, B. t. u.			10,215		
Calculated from ultimate analysis, calories	5,781		5,743		
Calculated from ultimate analysis, B. t. u.	10,406		10,337		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Results figured from sample from steaming test 342.

STEAMING TESTS.

Illinois No. 26 (run of mine).

		Test 341.	Test 342.
Size as used:			
3½ inches	per cent		61.0
3 inches	do	58.6	
2½ inches to 1 inch	do		17.1
1½ inches to 1 inch	do	19.9	
½ inch to 1 inch	do	8.9	9.2
¼ inch to ½ inch	do	4.4	5.8
Under ¼ inch	do	8.2	6.9
Duration of test	hours	10.0	8.87
Kind of grate		Rocking.	Rocking.
Heating value of coal	B. t. u. per pound dry coal	12,029	12,260
Force of draft:			
Under stack damper	inch water	0.65	0.64
Above fire	do	.34	.30
Furnace temperature	°F		2,264
Dry coal used per square foot of grate surface per hour	pounds	20.91	23.02
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	2.84	3.16
Percentage of rated horsepower of boiler developed		79.7	88.6
Water apparently evaporated per pound of coal as fired	pounds	5.52	5.40
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	6.56	6.47
Per pound of dry coal	do	7.58	7.67
Per pound of combustible	do	9.29	9.29
Efficiency of boiler, including grate	per cent	60.85	60.42
Coal as fired:			
Per indicated horsepower hour	pounds	4.31	4.37
Per electrical horsepower hour	do	5.32	5.40
Dry coal:			
Per indicated horsepower hour	do	3.73	3.69
Per electrical horsepower hour	do	4.61	4.55

PRODUCER-GAS TEST.

Illinois No. 26 (run of mine).

Test 126.—Duration of test, 50 hours; average electrical horsepower, 174.5; average B. t. u. per cubic foot of gas, 147.2; total coal fired, 16,050 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.96	1.70	1.39
Developed at switchboard	1.84	1.59	1.30
Per brake horsepower:			
Commercially available	1.67	1.45	1.18
Developed at engine	1.56	1.36	1.11
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.13	1.85	1.51
Developed at switchboard	2.00	1.73	1.41
Per brake horsepower:			
Commercially available	1.81	1.57	1.28
Developed at engine	1.70	1.47	1.20

Analyses

Coal.		*Gas by volume.*	
Moisture	13.29	Carbon dioxide (CO_2)	10.5
Volatile matter	32.02	Carbon monoxide (CO)	19.4
Fixed carbon	38.81	Hydrogen (H_2)	15.5
Ash	15.88	Methane (CH_4)	1.7
Sulphur	3.52	Nitrogen (N_2)	52.5
		Ethylene (C_2H_4)	.4

WASHING AND COKING TESTS.

Illinois No. 26 (run of mine).

Washing test 164.—Size as used, crushed to 2 inches. Jig used, Stewart. Raw coal 18,000 pounds; washed coal, 16,000 pounds; refuse, 2,000 pounds.

Coking test 143.—Size as used, washed, finely crushed. Duration of test, 59 hours. Coal charged, 11,750 pounds; coke produced, 5,850 pounds; 49.79 per cent. Breeze produced, 1,250 pounds; 10.64 per cent. Total yield, 60.43 per cent. Soft dense coke. Coal particles stuck together after volatile expelled.

Analyses.

	Washing test 164.		Coking test 143.	
	Raw coal.[a]	Washed coal.	Coal.	Coke.
Moisture	15.68	15.96	15.18	5.27
Volatile matter	32.41	.....	33.46	3.35
Fixed carbon	39.82	.....	41.53	75.98
Ash	12.09	9.40	9.83	15.40
Sulphur	3.51	2.76	2.73	2.80

[a] Sample taken from steaming test 342.

ILLINOIS NO. 27.

Bituminous coal from Auburn, Sangamon County, on the Chicago and Alton Railroad, was designated Illinois No. 27. The coal is reached by shaft at this place, and averages 6 feet 6 inches in thickness.

This sample consisted of run-of-mine coal and was shipped under the supervision of John W. Groves. It was used in making steaming tests 353 and 354; producer-gas test 127; washing test 165; and coking test 144 (washed coal).

Two mine samples were taken for chemical analysis. Sample 2897 was taken 2,000 feet southeast of the shaft, where the coal measured 6 feet 10 inches in thickness. Sample 2898 was taken 1,400 feet south of the shaft, where the coal measured 6 feet 10 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 27.

	Mine sample.		Car sample.[a]	Steaming test.[b]	
				353.	354.
Laboratory No	2897	2898	3052		
Air-drying loss	10.20	10.50	10.00		
Proximate:					
Moisture	14.29	14.18	16.00	16.00	15.82
Volatile matter	37.17	34.85	32.41	32.41	32.50
Fixed carbon	40.36	41.11	37.82	37.82	37.73
Ash	8.18	9.86	13.77	13.77	13.95
Sulphur	4.41	4.36	4.05	4.05	4.86
Ultimate:					
Hydrogen			5.55	4.49	4.43
Carbon			53.89	64.15	63.29
Nitrogen			.91	1.08	1.07
Oxygen			21.83	9.07	8.94
Ash				16.39	16.57
Sulphur				4.82	5.70
Calorific value:					
Determined — calories	6,115		5,522		
Determined — B. t. u.	11,007		9,940		
Calculated from ultimate analysis — calories			5,417		
Calculated from ultimate analysis — B. t. u.			9,751		

[a] Sample taken from steaming test 353.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois No. 27.

		Test 353.	Test 354.
Size as used:			
Over 1 inch	per cent	72.4	34.6
½ inch to 1 inch	do	11.1	25.7
¼ inch to ½ inch	do	6.8	17.6
Under ¼ inch	do	9.7	22.1
Average diameter	inches	2.29	.93
Duration of test	hours	10.00	10.02
Heating value of coal	B. t. u. per pound dry coal	11.831	11,713
Force of draft:			
Under stack damper	inch water	0.60	0.72
Above fire	do	.18	.17
Furnace temperature	°F	2,360	2,162
Dry coal used per square foot of grate surface per hour	pounds	19.83	19.26
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	3.14	3.08
Percentage of rated horsepower of boiler developed		88.0	86.4
Water apparently evaporated per pound of coal as fired	pounds	5.57	5.60
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	6.66	6.75
Per pound of dry coal	do	7.93	8.02
Per pound of combustible	do	9.65	9.85
Efficiency of boiler, including grate	per cent	64.73	66.12
Coal as fired:			
Per indicated-horsepower hour	pounds	4.24	4.19
Per electrical-horsepower hour	do	5.24	5.17
Dry coal:			
Per indicated-horsepower hour	do	3.56	3.53
Per electrical-horsepower hour	do	4.40	4.36

Illinois No. 27 (run of mine).

Test 127.—Average electrical horsepower, [illegible].8; average B. t. u. per cubic foot of gas, 122.5; total coal fired, 16,050 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.83	2.51	2.12
Developed at switch board	2.57	2.28	1.92
Per brake horsepower:			
Commercially available	2.40	2.13	1.80
Developed at engine	2.19	1.94	1.63
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	3.06	2.72	2.29
Developed at switch board	2.78	2.47	2.08
Per brake horsepower:			
Commercially available	2.60	2.31	1.95
Developed at engine	2.36	2.10	1.77

Analyses.

Coal.		*Gas by volume.*	
Moisture	11.35	Carbon dioxide (CO_2)	12.4
Volatile matter	33.59	Carbon monoxide (CO)	15.0
Fixed carbon	41.20	Hydrogen (H_2)	12.9
Ash	13.86	Methane (CH_4)	1.6
Sulphur	4.54	Nitrogen (H_2)	57.7
		Ethylene (C_2H_4)	.4

WASHING AND COKING TESTS.

Illinois No. 27 (run of mine).

Washing test 165.—Size as used, crushed to 2 inches. Jig used, Stewart. Raw coal, 18,000 pounds; washed, 15,545 pounds; refuse, 2,455 pounds.

Coking test 144.—Size as used, washed, finely crushed. Duration of test, 53 hours; coal charged, 11,550 pounds; coke produced, 5,067 pounds; 43.87 per cent; breeze produced, 405 pounds; 3.51 per cent. Total yield. 47.38 per cent. Soft, dense coke; very little cell structure; high sulphur.

Analyses.

	Washing test 165.		Coking test 144.	
	Raw coal.[a]	Washed coal.	Coal.	Coke.
Moisture	16.00	16.11	16.39	3.51
Volatile matter	32.41	.....	34.26	1.55
Fixed carbon	37.82	.....	41.57	81.14
Ash	13.77	7.76	7.78	13.80
Sulphur	4.05	3.26	3.22	3.40

[a] Sample taken from steaming test 353.

ILLINOIS NO. 28.

Bituminous coal from bed No. 7 at Herrin, Williamson County, was designated Illinois No. 28. This coal, as worked at a depth of 167 feet at this place, averages 6 feet 11 inches in thickness.

Three shipments of coal for testing purposes were made from this mine. Illinois No. 28 A consisted of No. 5 washed coal, was shipped uninspected, and was used in steaming test 459 (on briquets) and in briquetting tests 140*, 141*, 142*, 143*, 162, and 163. Illinois No. 28 B consisted of unwashed screenings shipped uninspected, and was used in steaming test 457 (on briquets) and briquetting tests 144*, 158*, 159, 160*, and 161. Illinois No. 28 C consisted of lump coal which passed over a 3-inch round shaking screen, was shipped under the supervision of K. M. Way, and was used in steaming tests 448 and 452, washing test 181, and coking test 166.

Two mine samples were taken for chemical analysis. Sample 3629 was taken 2,400 feet west of the shaft, where the coal measured 7 feet in thickness. Sample 3632 was taken 2,250 feet northwest of the shaft, where the coal measured 6 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 28.

	Mine sample.		Car sample (C).	Steaming tests.[a]				Briquetting tests.[b]				
				A.	B.	C.		A.			B.	
				459.	457.	448.	452.	140*.	142*.	143*.	144*.	158*, 159, and 160*.
Laboratory No.	3629	3632	3789	.....	4121	.....	.....	.....	.....	4066	4144	4150
Air-drying loss	.....	.....	3.00	.....	.....	.....	.....	.....	.....	.....	.....	.....
Proximate:												
Moisture	8.72	8.88	7.78	7.32	5.81	4.82	7.02	5.81	5.75	5.78	6.38	5.45
Volatile matter	30.38	29.49	29.85	30.72	30.86	30.81	29.93	30.31	31.06	30.58	31.07	31.65
Fixed carbon	53.28	53.60	52.39	49.84	52.41	53.82	53.51	49.58	51.50	51.02	51.19	51.74
Ash	7.62	8.03	9.98	12.12	10.92	10.55	9.54	14.30	12.61	12.62	11.36	11.16
Sulphur	1.00	.99	1.32	1.29	2.03	1.47	1.18	1.25	1.21	.95	1.55	2.04
Ultimate:												
Hydrogen	.....	.....	5.06	4.21	4.60	4.54	4.59	4.21	4.16	4.35	4.22	4.19
Carbon	.....	.....	67.45	71.88	71.92	72.85	73.75	69.69	71.92	71.89	71.82	71.62
Nitrogen	.....	.....	1.21	1.59	1.37	1.30	1.32	1.36	1.35	1.36	1.39	1.43
Oxygen	.....	.....	14.98	7.85	8.36	8.68	8.81	8.23	7.95	8.00	8.78	8.80
Ash	.....	.....	.....	13.08	11.59	11.09	10.26	15.18	13.34	13.39	12.13	11.80
Sulphur	.....	.....	.....	1.39	2.10	1.54	1.27	1.33	1.28	1.01	1.66	2.16
Calorific value determined (as received) calories	6,77[illegible]	.....	6,644	.....	.....	.....	.....	.....	.....	.....	.....	.....
Calorific value determined (as received) B. t. u.	12,200	.....	11,959	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Illinois No. 28.

	A.	B.	C.	
	Test 459 (w.).	Test 457.	Test 448.	Test 452.
Size as used:				
Over 1 inch ... per cent	(a)	(a)	32.3	58.4
½ inch to 1 inch ... do			22.1	21.3
¼ inch to ½ inch ... do			13.7	9.0
Under ¼ inch ... do			31.9	11.13
Average diameter ... inches			.79	1.12
Duration of test ... hours	9.95	9.13	10.03	10.00
Heating value of fuel ... B. t. u. per pound dry fuel	12,557	12,859	12,920	13,070
Force of draft:				
Under stack damper ... inch water	0.80	0.81	0.76	0.74
Above fire ... do	.15	.16	.17	.14
Furnace temperature ... °F	2,601	2,606	2,862	2,833
Dry fuel used per square foot of grate surface per hour, pounds	18.72	19.85	22.52	21.97
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.13	3.42	3.88	3.94
Percentage of rated horsepower of boiler developed	87.7	95.9	108.8	110.5
Water apparently evaporated per pound of fuel as fired, pounds	6.43	6.78	7.01	6.97
Water evaporated from and at 212° F.:				
Per pound of fuel as fired ... do	7.75	8.13	8.21	8.35
Per pound of dry fuel ... do	8.36	8.64	8.63	8.98
Per pound of combustible ... do	9.79	10.11	9.99	10.36
Efficiency of boiler, including grate ... per cent	64.29	64.99	64.50	66.35
Fuel as fired:				
Per indicated horsepower hour ... pounds	3.65	3.48	3.44	3.39
Per electrical horsepower hour ... do	4.50	4.29	4.25	4.18
Dry fuel:				
Per indicated horsepower hour ... do	3.38	3.27	3.28	3.15
Per electrical horsepower hour ... do	4.18	4.04	4.05	3.89

[a] See p. 109.

Remarks.—Test 459 on briquets from tests 162 and 163 (equal weights) and English briquets; fired whole; no smoke from either kind. Test 457 on briquets from tests 159 and 161 (equal weights); made 4 per cent black smoke.

WASHING AND COKING TEST.

Illinois No. 28 C (lump).

Washing test 181.—Size as used, 2-inch; jig used, Stewart; raw coal, 24,000 pounds; washed coal, 19,925 pounds, 74 per cent; refuse, 4,075 pounds, 26 per cent.

Coking test 166.—Size as used, washed, finely crushed. Duration of test, 60 hours. Coal charged, 12,600 pounds; coke produced, 6,350 pounds, 50.40 per cent; breeze produced, 661 pounds, 5.25 per cent. Total yield, 55.65 per cent; dark-gray color; poor, dense coke.

Analysis.

	Washing test 181.		Coking test 166.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	7.78	9.75	9.37	2.82
Volatile matter	29.85	.....	30.38	.60
Fixed carbon	52.39	.....	53.36	86.12
Ash	9.98	7.12	6.89	10.46
Sulphur	1.32	1.05	1.09	.98
Phosphorus	.....	.....	.....	.0075

BRIQUETTING TESTS.

Illinois No. 28.

Tests 140, 141*, 142*, 143*, 162, 163 (coal A, washed screenings.)*—Size as used: $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 3.0 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 13.0 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 20.2 per cent; through $\frac{1}{40}$ inch, 63.8 per cent. There was no appreciable difference in briquets with 6, 7, and 8 per cent binder made on English machine and 8 per cent on Renfrow machine. Renfrow briquets made with less than 8 per cent binder were not satisfactory. The satisfactory briquets had hard, smooth outer surfaces, broke with clean rough fracture without crumbling, and edges were hard and sharp. Renfrow briquets could be handled warm and piled without crushing.

For analyses of briquets from tests 162 and 163 see page 108 (steaming test 459).

	Test 140*.	Test 141*.	Test 142*.	Test 143*.	Test 162.	Test 163.
Details of manufacture:						
Machine used	Eng.	Eng.	Eng.	Renf.	Renf.	Eng.
Temperature of briquets ....°F.	185	185	185	131	131	185
Binder—						
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	3410	3410	3410	3410	3885	3885
Amount ....per cent.	6	7	8	8	8	7
Weight of—						
Fuel briquetted ....pounds.	16,000	16,000	16,000	134,000	40,000	8,000
Briquets, average ....do.	3.44	3.54	3.45	.502	.463	3.62
Heat value per pound—						
Fuel as received ....B. t. u.	10,611	10,611	10,611	10,611	10,611	10,611
Fuel as fired ....do.	.....	11,567	11,927	12,026	11,637	11,637
Binder ....do.	16,478	16,478	16,478	16,478	16,870	16,870
Drop test (1-inch screen):						
Held ....per cent.	.....	.....	.....	.....	61.5	.....
Passed ....do.	.....	.....	.....	.....	38.5	.....
Tumbler test (1-inch screen):						
Held ....do.	.....	.....	.....	.....	73.5	.....
Passed (fines) ....do.	.....	.....	.....	.....	26.5	.....
Fines through 10-mesh sieve ....do.	.....	.....	.....	.....	94.5	.....
Weathering test:						
Time exposed ....days.	182	182	182	173	127	173
Condition	A.	B.	A.	B.	B.	B.
Water absorption:						
In 19 days ....per cent.	.....	.....	.....	.....	13.6	.....
Average for first 5 days ....do.	.....	.....	.....	.....	1.84	.....
Specific gravity (apparent)	.....	.....	.....	.....	1.041	.....

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 143*.
Laboratory No	3410	3409	4066
Air-drying loss ....per cent.	.....	9.30	.....
Extracted by CS_2:			
Air dried ....do.	.....	.23	.....
As received ....do.	79.98	.21	9.15
Pitch in briquets, as received ....do.	.....	.....	11.21

Tests 144, 158*, 159, 160*, 161 (coal B, raw screenings).*—Size as used: Over $\frac{1}{4}$ inch, 0.4 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 3.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 13.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 24.8 per cent; through $\frac{1}{40}$ inch, 57.6 per cent. These briquets showed the same characteristics as those made from Illinois No. 28 A, except that when cold their surfaces were tougher and less liable to break down from abrasion than those of the briquets from the washed fuel. For analyses of briquets from test 161 see page 108 (steaming test 457).

	Test 144*.	Test 158*.	Test 159.	Test 160*.	Test 161.
Details of manufacture:					
Machine used	Renf.	Eng.	Eng.	Eng.	Renf.
Temperature of briquets ... °F.	131	185	185	185	131
Binder—					
Kind	w. g. p.	c. t. p.	c. t. p.	c. t. p.	w. g. p.
Laboratory No. (see p. 40)	3486, 3624	3692	3692	3692	3692, 3885
Amount ... per cent.	8	6	7	8	8
Weight of—					
Fuel briquetted ... pounds.	123,000	20,000	28,000	20,000	30,000
Briquets, average ... do.	0.524	3.50	3.51	3.63	0.481
Heat value per pound—					
Fuel as received ... B. t. u.	11,329	11,329	11,329	11,329	11,329
Fuel as fired ... do.	12,094	12,161	12,161	12,161	12,092
Binder ... do.	[a] 16,300	16,103	16,103	16,103	16,870
Drop test (1-inch screen):					
Held ... do.	49.0	77.9	72.3	80.6	41.0
Passed ... do.	51.0	22.1	27.7	19.4	59.0
Tumbler test (1-inch screen):					
Held ... do.	79.0	77.8	72.1	66.4	59.5
Passed (fines) ... do.	21.0	22.2	27.9	33.6	40.5
Fines through 10-mesh sieve ... do.	85.0	80.0	87.7	78.3	89.5
Weathering test:					
Time exposed ... days.	141	143	137	137	112
Condition	C.	B.	B.	B.	C.
Water absorption:					
In 19 days ... per cent.	15.5	14.3	12.6	13.9	16.0
Average for first 5 days ... do.	1.98	1.40	1.30	1.40	2.14
Specific gravity (apparent)	1.075	1.092	1.112	1.075	1.038

[a] Equal weights of two binders were used and the calorific value determined from the separate calorific values of the binders.

Extraction analyses.

	Pitches.				Fuel.	Briquets.		
						Test 144*.	Tests 158*, 159, 160*.	Test 161.
Laboratory No.	3486	3624	3692	3885	3423	4144	4150	4121
Air-drying loss ... per cent.					6.20			2.90
Extracted by CS_2:								
Air dried ... do.					.25			5.96
As received ... do.	85.57	99.60	69.71	95.20	.23	7.54	5.12	5.79
Pitch in briquets, as received ... do.						8.57	7.02	6.77

ILLINOIS NO. 29.

Bituminous coal from bed No. 5 at Livingston, Madison County, was designated Illinois No. 29. This coal, as worked at a depth of 286 feet at this place, averages 6 feet 10 inches in thickness.

Two samples were shipped under the supervision of K. M. Way, as follows: Illinois No. 29 A consisted of screenings through a 2-inch shaking screen and was used in steaming test 465 (on briquets); washing tests 183 and 184; coking tests 169 and 170; cupola tests 150, 157, and 164; and briquetting tests 170 and 171†. Illinois No. 29 B consisted of run-of-mine coal and was used in steaming tests 460, 461, and 466 (on briquets); producer-gas test 139, and briquetting test 175†.

Two mine samples were taken for chemical analysis. Sample 3911 was taken 1,600 feet south of the shaft, where the coal measured 7 feet 1½ inches in thickness. Sample 3913 was taken 1,200 feet

northwest of the shaft, where the coal measured 6 feet 6¾ inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 29.

	Mine samples.		Car samples.			Steaming tests.[a]				Briquetting test 171† (A).[b]
			B.	A.	B.	A.	B.			
						465.	460.	461.	466.	
Laboratory No.	3911	3913	3958	3963	3980	4233	.....	.....	4245	.....
Air-drying loss	.....	.....	7.30	8.60	5.50	.....	.....	.....	.....	.....
Proximate:										
Moisture	14.25	12.69	12.47	13.10	12.25	14.23	11.09	12.41	10.00	12.29
Volatile matter	35.52	37.40	33.12	30.73	33.76	34.63	33.68	35.42	36.33	37.16
Fixed carbon	40.79	41.15	41.85	40.12	41.66	43.96	41.17	42.15	43.01	43.99
Ash	9.44	8.76	12.56	16.00	12.33	7.18	14.06	10.02	10.66	6.56
Sulphur	3.72	3.62	4.37	4.17	4.42	2.84	4.63	3.51	3.24	3.56
Ultimate:										
Hydrogen	.....	.....	5.37	5.26	5.44	4.78	4.45	4.77	4.82	4.91
Carbon	.....	.....	57.17	54.26	58.30	72.39	63.96	68.47	69.45	72.23
Nitrogen	.....	.....	1.00	.89	.80	1.08	1.11	1.20	1.26	1.07
Oxygen	.....	.....	19.53	19.42	18.71	10.07	9.46	10.11	9.03	10.26
Ash	.....	.....	.....	.....	.....	8.37	15.81	11.[illegible]	11.84	7.47
Sulphur	.....	.....	.....	.....	.....	3.31	5.21	4.01	3.60	4.06
Calorific value determined (as received) calories	6,051	6,242	5,926	5,546	5,955	.....	.....	.....	.....	.....
Calorific value determined (as received) B. t. u.	10,892	11,236	10,667	9,983	10,719	.....	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Illinois No. 29.

	A.	B.		
	Test 465.	Test 460.	Test 461.	Test 466.
Size as used:				
Over 1 inch ... per cent	See p. 114.	34.1	51.4	See p. 114.
½ inch to 1 inch ... do		21.5	22.4	
¼ inch to ½ inch ... do		13.2	10.7	
Under ¼ inch ... do		31.2	15.5	
Average diameter ... inches		0.81	1.04	
Duration of test ... hours	9.98	10.05	5.42	10.07
Heating value of fuel ... B. t. u. per pound dry fuel	13,120	11,945	12,728	12,762
Force of draft:				
Under stack damper ... inch water	0.81	0.80	0.84	0.82
Above fire ... do	.15	.18	.18	.16
In ash pit ... do	.....	.....	.....	.....
Furnace temperature ... ° F	2,665	2,759	2,816	2,784
Dry fuel used per square foot of grate surface per hour ... pounds	20.35	21.38	22.32	22.32
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.62	3.44	3.72	3.90
Percentage of rated horsepower of boiler developed	101.5	96.3	104.2	109.2
Water apparently evaporated per pound of fuel as fired, pounds	6.34	5.93	6.05	6.52
Water evaporated from and at 212° F.:				
Per pound of fuel as fired ... pounds	7.65	7.16	7.31	7.87
Per pound of dry fuel ... do	8.91	8.05	8.34	8.74
Per pound of combustible ... do	9.89	9.88	9.58	10.03
Efficiency of boiler, including grate ... per cent	65.58	65.08	63.28	66.14
Fuel as fired:				
Per indicated horsepower hour ... pounds	3.70	3.95	3.87	3.59
Per electrical horsepower hour ... do	4.56	4.88	4.78	4.44
Dry fuel:				
Per indicated horsepower hour ... do	3.17	3.51	3.39	3.24
Per electrical horsepower hour ... do	3.92	4.34	4.19	3.99

Remarks.—Test 465 on English and Renfrow briquets from tests 170 and 171† (equal weights) burned with medium-length flame, making 6 per cent black smoke; 42 per cent clinker, very hard, brittle, and of a dark-gray color and glassy fracture. Test 466 on briquets from test 175† burned with a hot fire, medium flame, making 13 per cent black smoke; 38 per cent clinker, gray, hard, porous; steam jet used to keep from sticking to grates; ash gray in color, gritty.

PRODUCER-GAS TEST.

Illinois No. 29 B (run of mine).

Test 139.—Size as used: Over 1 inch, 66 per cent; ½ inch to 1 inch, 17 per cent; ¼ inch to ½ inch, 7 per cent; under ¼ inch, 10 per cent. Duration of test, 50 hours. Average electrical horsepower, 194.3; average B. t. u. per cubic foot of gas, 141.2; total coal fired, 17,250 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.86	1.63	1.40
Developed at switchboard	1.70	1.56	1.34
Per brake horsepower:			
Commercially available	1.58	1.39	1.19
Developed at engine	1.51	1.33	1.14
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.00	1.75	1.51
Developed at switchboard	1.91	1.67	1.44
Per brake horsepower:			
Commercially available	1.70	1.49	1.28
Developed at engine	1.62	1.42	1.22

Analyses.

Coal.		*Gas by volume.*	
Moisture	12.25	Carbon dioxide (CO_2)	11.4
Volatile matter	33.76	Carbon monoxide (CO)	17.3
Fixed carbon	41.66	Hydrogen (H_2)	14.0
Ash	12.33	Methane (CH_4)	2.0
Sulphur	4.42	Nitrogen (N_2)	54.8
		Ethylene (C_2H_4)	.5

WASHING AND COKING TESTS.

Illinois No. 29 A (screenings).

Washing tests.

		Test 183.	Test 184.
Jig used		Stewart.	Stewart.
Raw coal	pounds	18,000	59,500
Washed coal	do	13,750	41,500
	per cent	76	70
Refuse	pounds	4,250	18,000
	per cent	24	30

Coking tests (on washed coal).

		Test 169.	Test 170.
Size as used		f. c.	f. c.
Duration of test	hours	74	54
Coal charged	pounds	12,010	11,680
Coke produced	do	4,950	4,950
	per cent	41.22	42.38
Breeze produced	pounds	684	338
	per cent	5.70	2.89
Total yield	do	46.92	45.27

Remarks.—Test 169: Poor, dense coke; high sulphur. Test 170: Better than test 169, but poor coke with high sulphur content.

Analyses.

	Washing test 183.		Washing test 184 (washed coal).	Coking test 169.		Coking test 170.	
	Raw coal.	Washed coal.		Coal.	Coke.	Coal.	Coke.
Moisture	13.10	15.86	15.86	15.63	0.72	18.39	2.78
Volatile matter	30.73	.....	.....	33.88	.90	32.87	.74
Fixed carbon	40.12	.....	.....	42.81	84.62	41.53	83.35
Ash	16.00	7.70	7.70	7.68	13.76	7.21	13.13
Sulphur	4.17	3.06	3.06	3.13	2.57	3.06	2.49

Cupola tests of coke made from Illinois No. 29 A coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
150	170	1.83	7	94.44	Coke	190	60	60	60	60	430
					Pig iron	760	560	560	560	560	3,000
157	170	1.83	6	97.22	Coke	190	78	78	77	77	500
					Pig iron	760	560	560	560	560	3,000
164	170	1.83	8	94.44	Coke	200	44	44	44	43	375
					Pig iron	800	550	550	550	550	3,000

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio, iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
150	10.59 a. m.	7	12	2,095	329	2,424	34	4,278	6.12	5.53	410	34
157	3.15 p. m.	7	10	2,195	466	2,661	31	5,150	6.02	5.37	178	58
164	11.10 a. m.	7	9	1,331	295	1,626	30	3,252	4.85	6.77	1,171	40

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (lbs.).	Silicon.		Manganese.		Sulphur.		Content of coke combined with iron melted (per cent).
			Percent.	Pounds.	Percent.	Pounds.	Percent.	Pounds.	
150	Pig iron	.....	2.12	51.39	0.178	4.315	0.059	1.4302	6.59
	Melted iron:								
	Amount	.....	1.91	46.30	.155	3.757	.086	2.0846	
	Gain or loss	.....	−9.90	−5.09	−12.93	−.558	+.027	+.6544	
	Coke	399	.....	.....	.....	.....	2.49	9.9351	
157	Pig iron	.....	2.12	56.41	.178	4.737	.059	1.5700	11.69
	Melted iron:								
	Amount	.....	1.84	48.96	.133	3.539	.108	2.8739	
	Gain or loss	.....	−13.21	−7.45	−25.29	−1.198	+.049	+1.3039	
	Coke	448	.....	.....	.....	.....	2.49	11.1552	
164	Pig iron	.....	2.10	34.15	.163	2.650	.098	1.5935	6.74
	Melted iron:								
	Amount	.....	1.68	27.32	.111	1.805	.133	2.1626	
	Gain or loss	.....	−20.00	−6.83	−31.90	−.845	+.035	+.5691	
	Coke	339	.....	.....	.....	.....	2.49	8.4411	

Cupola tests of coke made from Illinois No. 29 A coal (washed)—Continued.

LADLE RECORD.

Ladle No.	Test 150.[a]		Test 157.[a]		Test 164.[b]		Ladle No.	Test 150.[a]		Test 157.[a]		Test 164.[b]	
	Lbs.	Time (a.m.).	Lbs.	Time (p.m.).	Lbs.	Time (a.m.).		Lbs.	Time (a.m.).	Lbs.	Time (p.m.).	Lbs.	Time (a. m.)
1	55	11.14	19	3.28	86	11.25	13	66	11.30	88	3.44	84	11.44
2	96	11.18	95	3.32	32	11.25½	14	99	11.30½	107	3.45	57	11.46
3	110	11.19	107	3.32½	93	11.28	15	97	11.31	97	3.45½	78	11.46½
4	69	11.23	86	3.33	88	11.28½	16	90	11.34	98	3.46	136	11.47
5	103	11.23½	87	3.36	52	11.29	17	98	11.34½	106	3.48	53	11.48
6	103	11.24	107	3.36½	90	11.30	18	100	11.35	102	3.48½	40	11.49
7	75	11.25	85	3.37	69	11.31	19	97	11.40	90	3.49	.....	.....
8	98	11.25½	81	3.40	65	11.38	20	94	11.40½	88	3.52	.....	.....
9	103	11.26	100	3.40½	83	11.38½	21	88	11.41	109	3.52½	.....	.....
10	70	11.27	80	3.41	82	11.39	22	92	11.43	85	3.53	.....	.....
11	102	11.27½	101	3.43	60	11.43	23	67	11.44	83	3.55	.....	.....
12	103	11.28	101	3.43½	83	11.43½	24	20	11.45	93	3.56	.....	.....

[a] Pig iron used from car 27633. [b] Pig iron used from car 131943.

Remarks.—Test 150: Temperature of iron, medium. Test 157: Iron hot. Test 164: Iron cold.

BRIQUETTING TESTS.

Illinois No. 29.

Tests 170 and 171† (coal A, washed screenings).—Size as used: Over ¼ inch, 3.6 per cent; $\frac{1}{16}$ inch to ¼ inch, 8.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 16.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 20.8 per cent; through $\frac{1}{40}$ inch, 50.8 per cent. Satisfactory briquets were made on both machines with 7 per cent binder. Briquets were very hard and tough, and broke with rough fracture and hard edges. Renfrow briquets were well molded and stood handling when warm. For analyses of briquets from test 170 see page 111 (steaming test 465).

Test 175† (coal B, raw, run of mine).—Size as used: Over ¼ inch, 3.2 per cent; $\frac{1}{16}$ inch to ¼ inch, 9.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 16.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 25.8 per cent; through $\frac{1}{40}$ inch, 44.8 per cent. The briquets were identical with those made of the washed coal, except that fracture was rougher and harder, as fuel did not crush so fine in grinding. For analyses of briquets from test 175†, see page 111 (steaming test 466).

	A.		B.
	Test 170.	Test 171†.	Test 175†.
Details of manufacture:			
Machine used	Eng.	Renf.	Renf.
Temperature of briquets ... °F.	203	131	131
Binder—			
Kind	w. g. p. c. t. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4319 4543	4543	4543
Amount ... per cent	7	7	7
Weight of—			
Fuel briquetted ... pounds	6,000	24,000	15,000
Briquets, average ... do	3.84	.437	.465
Heat value per pound—			
Fuel as received ... B. t. u.	11,844	11,844	10,667
Fuel as fired ... do	11,254	11,671	11,486
Binder ... do	[a] 16,554	16,969	16,969
Drop test (1-inch screen):			
Held ... per cent	74.4	47.0	50.5
Passed ... do	25.6	53.0	49.5
Tumbler test (1-inch screen):			
Held ... per cent	94.0	75.0	77.5
Passed (fines) ... do	.06	25.0	22.5
Fines through 10-mesh sieve ... do	81.2	87.3	90.2
Weathering test:			
Time exposed ... days	56	55	53
Condition	C.	B.	B.
Water absorption:			
In 19 days ... per cent	17.0	21.5	18.8
Average for first—			
2 days ... do	5.15	5.05	.....
5 days ... do	.....	.....	2.42
Specific gravity (apparent)	1.053	.969	1.042

[a] *Equal* weights of two pitches were used and the calorific value determined from the separate calorific values of these pitches.

Extraction analyses.

	Pitches.		A.			B.	
			Fuel.	Briquets.		Fuel.	Briquets, test 175†.
				Test 170.	Test 171†.		
Laboratory No	4319	4543	3963	4233	4581	3958	4245
Air-drying loss.....per cent	.....	.....	8.60	11.80	10.40	7.30	7.80
Extracted by CS_2:							
Air-dried.....do	.....	.....	.83	6.61	7.57	.99	6.92
As received.....do	66.25	99.66	.76	5.83	6.77	.92	6.38
Pitch in briquets, as received, per cent	.....	.....	.....	6.47	6.09	.....	5.53

ILLINOIS NO. 30.

Bituminous coal from bed No. 7 at Shiloh station, St. Clair County, on the Southern Railway, was designated Illinois No. 30. The coal as worked at a depth of 126 feet at this place averages 6 feet 8 inches in thickness.

One sample, shipped under the supervision of K. M. Way, consisted of nut coal through a 3-inch and over a 2-inch shaking screen, and was used in steaming test 511 (on briquets); producer-gas test 157; washing tests 190 and 190a; and briquetting tests 225, 226, and 228.

Two mine samples were taken for chemical analysis. Sample 3910 was taken 900 feet southwest of the shaft, where the coal measured 6 feet 9 inches in thickness. Sample 3912 was taken 800 feet northeast of the shaft, where the coal measured 6 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 30.

		Mine samples.		Car sample.	Steaming test 511.[a]
Laboratory No		3910	3912	4364	4714
Air-drying loss		2.30	.....	8.70	.....
Proximate:					
Moisture		10.73	9.88	11.69	9.75
Volatile matter		39.60	42.26	35.70	39.25
Fixed carbon		40.41	37.05	39.42	42.69
Ash		9.26	10.81	13.19	8.13
Sulphur		4.12	3.83	4.38	3.21
Ultimate:					
Hydrogen		.....	.....	5.46	4.80
Carbon		.....	.....	57.15	71.76
Nitrogen		.....	.....	.94	1.13
Oxygen		.....	.....	18.88	9.60
Ash		.....	.....	.....	9.21
Sulphur		.....	.....	.....	3.56
Calorific value determined (as received)	calories	.....	6,355	5,944	.....
	B. t. u	.....	11,439	10,699	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Illinois No. 30 (washed).

		Test 511.
Duration of test	hours	8.58
Heating value of fuel	B. t. u. per pound dry fuel	13,271
Force of draft:		
Under stack damper	inch water	0.87
Above fire	do	.19
Dry fuel used per square foot of grate surface per hour	pounds	20.94
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.59
Percentage of rated horsepower of boiler developed		100.7
Water apparently evaporated per pound of fuel as fired	pounds	6.41
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	do	7.76
Per pound of dry fuel	do	8.60
Per pound of combustible	do	9.59
Efficiency of boiler, including grate	per cent	62.58
Fuel as fired:		
Per indicated horsepower hour	pounds	3.64
Per electrical horsepower hour	do	4.50
Dry fuel:		
Per indicated horsepower hour	do	3.29
Per electrical horsepower hour	do	4.06

Remarks.—Test made on English briquets from tests 225 and 226 (equal parts). Fuel burned slowly with hot fire, medium flame, and no smoke; 40 per cent clinker.

PRODUCER-GAS TEST.

Illinois No. 30 (washed).

Test 157.—Duration of test, 50 hours. Average electrical horsepower, 199; average B. t. u. per cubic foot of gas, 154.4; total coal fired, 16,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.69	1.60	1.44
Developed at switch board	1.63	1.54	1.38
Per brake horsepower:			
Commercially available	1.44	1.36	1.22
Developed at engine	1.38	1.31	1.17
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.78	1.68	1.51
Developed at switch board	1,71	1.61	1.45
Per brake horsepower:			
Commercially available	1.51	1.43	1.28
Developed at engine	1.45	1.37	1.23

Analyses.

Coal.

Moisture	5.59
Volatile matter	39.30
Fixed carbon	45.45
Ash	9.66
Sulphur	3.37

Gas by volume.

Carbon dioxide (CO_2)	9.3
Carbon monoxide (CO)	19.6
Hydrogen (H_2)	13.8
Methane (CH_4)	2.0
Nitrogen (N_2)	54.7
Ethylene (C_2H_4)	.6

WASHING TESTS.

Illinois No. 30.

	Test 190.	Test 190a.			Test 190.	Test 190a.
Duration of test.....hours..	2	4	Raw coal.....tons..		15	12.45
Size as used..through screen.	2½-inch.	1-inch.	Washed coal.....	....do....	11.60	10.1
Jig adjustment:				per cent..	77	81
Make or number.....	Stewart.	Special.	Refuse.....	tons.....	3.40	2.35
Speed.....r. p. m..	35	70		per cent..	23	19
Stroke.....inches..	6	2½				

Analyses.

Sample tested.		Lab. No.	Moisture.	Ash.		Sulphur.	
				Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample.....		4364	11.69	13.19	.....	4.38	.....
Washed coal.....	test 190..	4379	12.36	9.44	28.3	3.26	25.6
	test 190a.	4621	13.67	7.89	40	3.15	28
Refuse, test 190a.....		.....	11.22	46.50	.....	9.59	.....

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float—		Sink (per cent).	Analyses.			
			To refuse.	To total sample.		Ash.		Sulphur.	
						Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1.....	¼	1.36	.....	73	27	7.10	46	3.29	23
2.....	¼	1.41	.....	84	16	8.69	34	3.29	23
3.....	¼	1.47	.....	88	12	8.98	31	3.33	23
4.....	¼	1.56	.....	90	10	9.59	27	3.41	22
On refuse (float)[a] of test 190a									
1.....	.....	1.36	15.8	2.98	.....	8.00	.....	3.12	.....
2.....	.....	1.40	20.18	4.13	.....	11.30	.....	3.42	.....
3.....	.....	1.45	29.90	5.63	.....	12.00	.....	3.43	.....
4.....	.....	1.51	33.50	6.31	.....	14.60	.....	4.63	.....

[a] Loss of good coal 2.98 per cent.

BRIQUETTING TESTS.

Illinois No. 30 (nut, washed).

Tests 225, 226, 228.—Size as used: Over ¼ inch, 2 per cent; $\frac{1}{10}$ inch to ¼ inch, 7 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 17.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 20.8 per cent; through $\frac{1}{40}$ inch, 52.8 per cent. Briquets satisfactory; had a hard, rough exterior and broke with a rough, uneven fracture, with crumbly edges. All briquets had a bluish color and fracture, which showed an excess of pitch. The Renfrow briquets showed insufficient pressure. For analysis of briquets from tests 225 and 226 see page 115 (steaming test 511).

	Test 225.	Test 226.	Test 228.
Details of manufacture:			
Machine used	Eng.	Eng.	Renf.
Temperature of briquettes ... °F.	185	185	158
Binder—			
Kind	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4806	4806	4806
Amount ... per cent.	6	7	8.5
Weight of—			
Fuel briquetted ... pounds.	6,000	6,000	6,500
Briquets, average ... do.	3.50	3.45	0.463
Heat value per pound—			
Fuel as received ... B. t. u.	11,921	11,921	11,921
Fuel as fired ... do.	11,977	11,977	(a)
Binder ... do.	16,864	16,864	16,864
Drop test (1-inch screen):			
Held ... per cent.	80.2	81.5	47.0
Passed ... do.	19.8	18.5	53.0
Tumbler test 1-inch screen):			
Held ... do.	75.9	79.0	82.5
Passed (fines) ... do.	24.1	21.0	17.5
Fines through 10-mesh sieve ... do.	82.6	85.0	95.0
Water absorption:			
In 13 days ... do.	8.6	8.5	.....
In 23 days ... do.	.....	.....	16.2
Average for first 5 days ... do.	1.35	1.98	2.10
Specific gravity (apparent)	1.087	1.080	1.060

[a] No test.

Extraction analyses.

	Pitch.	Fuel.	Briquets, tests 225, 226.
Laboratory No.	4806	4364	4714
Air-drying loss ... per cent.	.....	8.70	5.30
Extracted by CS_2:			
Air-dried ... do.	.....	.65	6.53
As received ... do.	96.90	.61	6.18
Pitch in briquets, as received ... do.	.....	.....	5.80

ILLINOIS NO. 31.

Bituminous coal from bed No. 6 at Warden, St. Clair County, on the Wabash Railroad, was designated Illinois No. 31. The coal, as worked at a depth of 300 feet at this place, averages 6 feet 8 inches in thickness.

One sample, shipped under the supervision of K. M. Way, consisted of screenings over a 1¼-inch shaking screen, and was used in steaming tests (on briquets) 489 and 491, and briquetting tests 185, 186, 224†, and 237†.

Two mine samples were taken for chemical analysis. Sample 4250 was taken 1,000 feet southwest of the shaft, where the coal measured 5 feet 10¾ inches in thickness. Sample 4251 was taken 1,600 feet north of the shaft, where the coal measured 7 feet 5¾ inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 31.

	Mine samples.		Car sample.	Steaming tests.[a]		Briquetting tests.[b]	
				489.	491.	224†.	237†.
Laboratory No	4250	4251	4376	4382	4397	.....	.....
Air-drying loss	8.00	9.40	9.70	.....	.....	.....	.....
Proximate:							
Moisture	13.17	14.38	13.10	14.52	10.81	9.17	6.98
Volatile matter	34.79	33.92	32.16	33.74	33.72	33.03	35.21
Fixed carbon	41.75	42.95	41.49	39.40	42.74	43.90	42.85
Ash	10.29	8.75	13.25	12.34	12.73	13.90	14.96
Sulphur	3.22	3.13	3.66	3.36	3.50	3.90	3.78
Ultimate:							
Hydrogen	.....	.....	5.44	4.68	4.54	4.33	3.57
Carbon	.....	.....	57.31	67.91	67.31	66.14	59.48
Nitrogen	.....	.....	1.03	1.12	1.04	1.01	.83
Oxygen	.....	.....	19.31	7.92	8.92	8.93	5.67
Ash	.....	.....	.....	14.44	14.27	15.30	25.03
Sulphur	.....	.....	.....	3.93	3.92	4.29	5.42
Calorific value determined (as received) B. t. u.	.....	6,032	5,774	.....	.....	.....	.....
	.....	10,858	10,363	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Illinois No. 31 (briquets).

	Test 489.	Test 491.
Duration of test ..... hours	9.47	9.75
Heating value of fuel ..... B. t. u. per pound dry fuel	12,303	12,335
Force of draft:		
Under stack damper ..... inch water	0.74	0.87
Above fire ..... do	.14	.20
Dry fuel used per square foot of grate surface per hour ..... pounds	21.16	21.65
Equivalent water evaporated per square foot of water-heating surface per hour ..... pounds	3.49	3.56
Percentage of rated horsepower of boiler developed	97.7	100.0
Water apparently evaporated per pound of fuel as fired ..... pounds	5.84	6.09
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ..... pounds	7.06	7.35
Per pound of dry fuel ..... do	8.25	8.24
Per pound of combustible ..... do	9.81	9.77
Efficiency of boiler, including grate ..... per cent	64.76	64.51
Fuel as fired:		
Per indicated horsepower hour ..... pounds	4.01	3.85
Per electrical horsepower hour ..... do	4.94	4.75
Dry fuel:		
Per indicated horsepower hour ..... do	3.43	3.43
Per electrical horsepower hour ..... do	4.23	4.24

Remarks.—Test 489 on briquets from test 186; test 491 on briquets from test 185: Fuel gave good results with thick fire; burned with a medium long flame, and gave 2 per cent black smoke. Renfrow briquets gave 47 per cent and English briquets 45 per cent clinker; brittle, porous, dark-gray color, and did not stick to grates.

BRIQUETTING TESTS.

Illinois No. 31 (screenings).

Tests 185, 186, 224†, 237†.—Size as used: Over $\frac{1}{4}$ inch, 3 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 8.5 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 17 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 24 per cent; through $\frac{1}{40}$ inch, 47.5 per cent. Briquets were porous, with soft surfaces, rough fracture, and easily crumbled edges. English briquets were handled from ma-

chine without breaking. Renfrow briquets were not satisfactory, owing to low pressure. This should be a good briquetting coal, although dirty. For analyses of briquets see page 119 (briquets from test 185 under "Steaming test 491," from test 186 under "Steaming test 489)."

	Test 185.	Test 186.	Test 224†.	Test 237†.
Details of manufacture:				
Machine used	Renf.	Eng.	Eng.	Renf.
Temperature of briquets ... °F.	140	176	149	149
Binder—				
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4543	4543	4683	4806
Amount ... per cent.	7	7	7	8
Weight of—				
Fuel briquetted ... pounds.	12,000	12,000	11,600	10,000
Briquets, average ... do.	0.460	3.77	3.91	0.442
Heat value per pound—				
Fuel as received ... B. t. u.	10,393	10,393	10,393	10,393
Fuel as fired ... do.	10,012	10,517	10,921	11,158
Binder ... do.	16,969	16,969	16,637	16,864
Drop test (1-inch screen):				
Held ... per cent.	64.5	79.7	24.2	34.5
Passed ... do.	35.5	20.3	75.8	65.5
Tumbler test (1-inch screen):				
Held ... do.	91.5	78.8	43.3	80.5
Passed (fines) ... do.	8.5	21.2	56.7	19.5
Fines through 10-mesh sieve ... do.	94.1	75.7	65.0	87.5
Weathering test:				
Time exposed ... days.	11	10	.....	.....
Condition	B.	A.	.....	.....
Water absorption:				
In 19 days ... per cent.	14.5	9.2	.....	.....
In 13 days ... do.	.....	.....	7.4	13.1
Average for first 3 days ... do.	2.70	1.60	1.67	1.93
Specific gravity (apparent)	1.053	1.144	1.167	1.123

Extraction analyses.

	Pitches.			Fuel.	Briquets.			
					Test 185.	Test 186.	Test 224†.	Test 237†.
Laboratory No.	4543	4683	4806	4376	4397	4382	4830	4890
Air-drying loss ... per cent.	.....	.....	.....	9.70	8.00	11.10	4.70	2.80
Extracted by CS_2:								
Air dried ... do.	.....	.....	.....	.49	7.07	6.99	7.05	7.80
As received ... do.	99.66	89.31	96.90	.44	6.50	6.21	6.72	7.58
Pitch in briquets, as received ... do.	.....	.....	.....	.....	6.11	5.86	7.08	7.41

ILLINOIS NO. 33.

Bituminous coal from bed No. 7 at Trenton, Clinton County, on the Baltimore and Ohio Railroad, was designated Illinois No. 33. This coal, as worked at a depth of 320 feet at this place, averages 5 feet 3 inches in thickness.

One sample, shipped under the supervision of K. M. Way, consisted of screenings through a 1½-inch shaking screen, and was used in steaming test 513 and briquetting tests 206, 207, 210, and 235†.

Two mine samples were taken for chemical analysis. Sample 4384 was taken 1,800 feet west of the shaft, where the coal measured 5 feet 6 inches in thickness. Sample 4385 was taken 2,000 feet northwest of the shaft, where the coal measured 5 feet in thickness.

CHEMICAL ANALYSES.

Illinois No. 33.

	Mine samples.		Steaming test 513.[a]	Briquetting test 235†.[b]
Laboratory No.	4384	4385	4728	4888
Air-drying loss	4.70	4.80	.....	3.90
Proximate:				
Moisture	14.45	15.06	11.50	9.47
Volatile matter	29.76	29.48	25.44	28.25
Fixed carbon	46.16	45.81	42.37	40.75
Ash	9.63	9.65	20.69	21.53
Sulphur	2.09	1.05	1.52	1.56
Ultimate:				
Hydrogen	.....	.....	3.72	3.93
Carbon	.....	.....	61.46	60.07
Nitrogen	.....	.....	1.02	1.03
Oxygen	.....	.....	8.70	9.47
Ash	.....	.....	23.38	23.78
Sulphur	.....	.....	1.72	1.72
Calorific value determined (as received) calories	.....	5,959	.....	5,423
Calorific value determined (as received) B. t. u.	.....	10,726	.....	9,761

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car samples.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TEST.

Illinois No. 33 (screenings).

		Test 513.[a]
Duration of test	hours	8.68
Heating value of fuel	B. t. u. per pound dry fuel	11,099
Force of draft:		
Under stack damper	inches water	1.01
Above fire	do	.10
In ash pit (forced draft)		.34
Furnace temperature	°F.	2,465
Dry coal used per square foot of grate surface per hour	pounds	26.41
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.23
Percentage of rated horsepower of boiler developed		90.7
Water apparently evaporated per pound of coal as fired	pounds	4.49
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	do	5.43
Per pound of dry fuel	do	6.13
Per pound of combustible	do	8.53
Efficiency of boiler, including grate	per cent	53.34
Fuel as fired:		
Per indicated horsepower hour	pounds	5.21
Per electrical horsepower hour	do	6.43
Dry fuel:		
Per indicated horsepower hour	do	4.61
Per electrical horsepower hour	do	5.69

[a] On English briquets.

BRIQUETTING TESTS.

Illinois No. 33 (screenings).

Tests 206, 207, 210, 235†.—Size as used: Over $\frac{1}{4}$ inch, 2.0 per cent; $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, 9.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 26.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 27.0 per cent; through $\frac{1}{40}$ inch, 34.8 per cent. The surface of all briquets was soft, fracture ragged, and edges easily broken. Greater percentage of binder had no apparent effect on appearance. Increased moisture content made a very soft, warm briquet, which hardened on cooling with a harder surface than those with less moisture. For analyses of briquets see above (briquets from tests 206 and 207 under "Steaming test 513").

	Test 206.	Test 207.	Test 210.	Test 235†.
Details of manufacture:				
Machine used	Eng.	Eng.	Renf.	Renf.
Temperature of briquets ... °F.	149	149	158	167
Binder—				
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4683	4683	4683	4806
Amount ... per cent.	7	6	7	8
Weight of—				
Fuel briquetted ... pounds.	8,000	7,000	6,000	15,000
Briquets, average ... do.	4.07	4.12	0.474	0.484
Heat value per pound—				
Fuel as received ... B. t. u.	7,634	7,634	7,634	7,634
Fuel as fired ... do.	9,823	9,823	(a)	9,761
Binder ... do.	16,637	16,637	16,637	16,864
Drop test (1-inch screen):				
Held ... per cent.	59.0	61.8	74.5	34.5
Passed ... do.	50.0	38.2	25.5	65.5
Tumbler test (1-inch screen):				
Held ... do.	55.6	60.3	94.0	89.5
Passed (fines) ... do.	44.4	39.7	6.0	10.5
Fines through 10-mesh sieve ... do.	66.6	72.1	90.8	94.7
Water absorption:				
In 10 days ... do.	7.6	9.4	11.1	6.5
Average for first 3 days ... do.	2.3	2.40	2.93	1.70
Specific gravity (apparent)	1.291	1.280	1.232	1.298

a No test.

Extraction analyses.

	Pitches.		Fuel.	Briquets.	
				Test 206.	Test 235†.
Laboratory No.	4683	4806	4385	4728	4888
Air-drying loss ... per cent.			4.80	5.50	3.90
Extracted by CS_2:					
Air-dried ... do.			0.29	5.22	7.66
As received ... do.	89.31	96.90	0.28	4.93	7.42
Pitch in briquets, as received ... do.				5.23	7.40

ILLINOIS NO. 34.

Bituminous coal from bed No. 5 at Harrisburg, Saline County, on the Big Four System, was designated Illinois No. 34. The coal, as worked at a depth of 165 feet at this place, averages 7 feet 1 inch in thickness.

Two samples were shipped under the supervision of K. M. Way, as follows: Illinois No. 34 A consisted of screenings over a 1¼-inch shaking screen, and was used in washing test 196. Illinois No. 34 B consisted of run-of-mine coal, and was used in steaming test 509, washing test 197, and coking test 190.

Two mine samples were taken for chemical analysis. Sample 4413 was taken 2,000 feet southwest of the shaft, where the coal measured 7 feet 3 inches in thickness. Sample 4414 was taken 1,000 feet north of the shaft, where the coal measured 6 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Illinois No. 34.

	Mine samples.		Car samples. A.	Car samples. B.	Steaming test 509.[a]
Laboratory No	4413	4414	4636	4622	.....
Air-drying loss	4.20	.....	6.60	5.80	.....
Proximate:					
Moisture	7.55	7.51	9.33	7.81	6.56
Volatile matter	33.85	32.81	30.92	33.54	34.15
Fixed carbon	51.45	52.20	47.86	50.27	51.57
Ash	7.15	7.48	11.89	8.38	7.72
Sulphur	1.56	1.58	2.76	2.36	2.17
Ultimate:					
Hydrogen	.....	.....	5.12	5.31	4.87
Carbon	.....	.....	62.85	67.40	74.00
Nitrogen	.....	.....	1.29	1.44	1.58
Oxygen	.....	.....	16.09	15.11	8.98
Ash	.....	.....	.....	.....	8.26
Sulphur	.....	.....	.....	.....	2.31
Calorific value determined (as received) calories	.....	7,048	6,429	6,899	.....
Calorific value determined (as received) B. t. u.	.....	12,686	11,572	12,418	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Illinois No. 34 B (run of mine).

		Test 509.
Size as used:		
Over 1 inch	per cent	44.3
½ inch to 1 inch	do	22.8
¼ inch to ½ inch	do	13.4
Under ¼ inch	do	19.5
Average diameter	inches	1.23
Duration of test	hours	9.00
Heating value of coal	B. t. u. per pound dry coal	13,621
Force of draft:		
Under stack damper	inch water	0.83
Above fire	do	.22
Dry coal used per square foot of grate surface per hour	pounds	21.50
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.79
Percentage of rated horsepower of boiler developed		106.2
Water apparently evaporated per pound of coal as fired	pounds	6.80
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.24
Per pound of dry coal	do	8.82
Per pound of combustible	do	9.79
Efficiency of boiler, including grate	per cent	62.53
Coal as fired:		
Per indicated horsepower hour	pounds	3.43
Per electrical horsepower hour	do	4.24
Dry coal:		
Per indicated horsepower hour	do	3.21
Per electrical horsepower hour	do	3.96

WASHING TESTS.

Illinois No. 34.

	Test 196 (A).	Test 197 (B).			Test 196 (A).	Test 197 (B).
Duration of test	4½	2	Raw coal	tons	24.65	14
Size as used—through screen	1 inch.	1 inch.	Washed coal	do	19.55	11.8
Jig adjustment:			Washed coal	per cent	80	85
Make or number	Special.	Special.	Refuse	tons	5.10	2.19
Speed p. m.	70	70	Refuse	per cent	20	15
Stroke inches	2½	2½				

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
A Raw coal, car sample	4636	9.33	11.89	.....	2.76	.....
A Washed coal, test 196	4709	8.68	77.44	37	2.19	21
A Refuse	.....	9.29	58.43	.....	11.91	.....
B Raw coal, car sample	4622	7.81	8.38	.....	2.36	.....
B Washed coal, test 197	4628	10.12	6.52	21	1.76	26
B Refuse	.....	15.35	61.00	.....	15.90	.....

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float—		Sink (per cent).	Analyses.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
A 1	¾	1.36	.....	84	16	6.07	49	1.90	31
A 2	¾	1.41	.....	88	12	6.12	48	1.83	34
A 3	¾	1.45	.....	90	10	7.06	41	2.18	21
A 4	¾	1.51	.....	92	8	7.10	40	1.97	29
B 1	1	1.35	.....	87	13	5.91	29	1.71	28
B 2	1	1.41	.....	90	10	6.15	27	1.64	31
B 3	1	1.46	.....	92	8	6.20	26	1.68	29
B 4	1	1.51	.....	92	8	7.23	14	2.17	8
On refuse (float):									
A[a] 1	.....	1.35	12.10	2.52	.....	6.95	.....	2.05	.....
A[a] 2	.....	1.41	13.59	2.82	.....	7.78	.....	2.33	.....
A[a] 3	.....	1.45	14.21	2.95	.....	9.58	.....	2.45	.....
A[a] 4	.....	1.51	16.78	3.43	.....	11.20	.....	3.05	.....
B[b] 1	.....	1.35	50	7.80	.....	6.27	.....	2.36	.....
B[b] 2	.....	1.40	52	8.14	.....	5.99	.....	2.50	.....
B[b] 3	.....	1.45	55	8.60	.....	7.40	.....	2.79	.....

[a] Loss of good coal, 2.52 per cent.

[b] Figures indicate that finer crushing is advantageous. Loss of "good coal" in the refuse will not exceed 1.75 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal.

COKING TEST.

Illinois No. 34 B (run of mine).

Test 190.—Size as used, washed, finely crushed. Duration of test, 51 hours. Coal charged, 12,980 pounds. Coke produced, 6,523 pounds; 50.25 per cent. Breeze produced, 316 pounds; 2.43 per cent. Total yield, 52.68 per cent. Coke, light gray and silvery. Yield low on account of burning to obtain heat; could be easily increased on better acquaintance. Good coke, but sulphur a little high.

Analyses.

	Coal.	Coke.
Moisture	9.91	0.19
Volatile matter	33.33	.35
Fixed carbon	50.65	87.91
Ash	6.11	11.55
Sulphur	1.75	1.48

INDIANA.

INDIANA NO. 1.[a]

A sample of bituminous screenings (through 1-inch screen) from Mildred, Sullivan County, on the Evansville and Terre Haute Railroad, was designated Indiana No. 1 B. This sample was used in briquetting test 217*†.

CHEMICAL ANALYSES.

Indiana No. 1 B.

	Briquetting test 217*†.[a]		Briquetting test 217*†.[a]
Proximate:		Ultimate:	
Moisture	8.29	Hydrogen	4.43
Volatile matter	30.55	Carbon	68.76
Fixed carbon	47.01	Nitrogen	1.19
Ash	14.15	Oxygen	7.59
Sulphur	2.38	Ash	15.43
		Sulphur	2.60

[a] Proximate analysis of fuel as received; ultimate analysis on dry basis.

BRIQUETTING TEST.

Indiana No. 1 B (screenings).

Test 217†.*—Size as used: Over ¼-inch, 5.0 per cent; $\frac{1}{10}$-inch to ¼-inch, 12.4 per cent; $\frac{1}{20}$-inch to $\frac{1}{10}$-inch, 22.4 per cent; $\frac{1}{40}$-inch to $\frac{1}{20}$-inch, 23.4 per cent; through $\frac{1}{40}$-inch, 36.8 per cent. Briquets with 8.5 per cent binder on Renfrew machine satisfactory when fuel was very dry; excess of moisture made a briquet that was soft when warm and crumbled easily when cold. Briquets had a porous, dull surface; rough fracture with ragged edges, but tough and hard, producing a small amount of slack in handling; showed no evidence of sticking together when piled warm.

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ... per cent	54.5
Temperature of briquets ... °F	141	Passed ... do	45.5
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held ... do	86.5
Laboratory No. (see p. 40)	4683	Passed (fines) ... do	13.5
Amount ... per cent	8.5	Fines through 10-mesh sieve ... do	95.0
Weight of—		Water absorption:	
Fuel briquetted	88,000	In 22 days ... do	14.0
Briquets, average ... per cent	0.485	Average for first 5 days ... do	1.92
Heat value per pound—		Specific gravity (apparent)	1.114
Fuel as received ... B. t. u.	9,866		
Fuel as fired ... do	11,444		
Binder ... do	16,637		

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 217*†.
Laboratory No.	4683	4590	4680
Air-drying loss ... per cent	.....	13.90	3.60
Extracted by CS_2:			
Air-dried ... do	.....	.81	7.35
As received ... do	89.31	.69	7.08
Pitch in briquets, as received ... do	.....	.....	7.21

[a] For other tests of fuel from this mine, made during 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 38, 80, 94, 119, 123, and 154; and Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 63, 212, 473, 1068, 1336, 1438, and 1463.

INDIANA NO. 5.[a]

A sample of bituminous screenings (through 1¼-inch bar screen) from Hymera, Sullivan County, on the Evansville and Terre Haute Railroad, was designated Indiana No. 5 B, and was used in briquetting tests 229* and 230*†.

CHEMICAL ANALYSES.

Indiana No. 5 B.

	Briquetting tests.[a]			Briquetting tests.[a]	
	229*.	230*†.		229*.	230*†.
Proximate:			Ultimate:		
Moisture	7.27	6.34	Hydrogen	4.49	4.62
Volatile matter	37.73	37.53	Carbon	68.47	68.06
Fixed carbon	44.37	44.74	Nitrogen	1.13	1.10
Ash	10.63	11.39	Oxygen	9.80	8.96
Sulphur	4.29	4.76	Ash	11.49	12.18
			Sulphur	4.62	5.08

[a] Proximate analysis of fuel as received; ultimate analysis on dry basis.

BRIQUETTING TESTS.

Indiana No. 5 B (screenings).

Tests 229 and 230*†.*—Size as used: Over ¼ inch, 1 per cent; $\frac{1}{10}$ inch to ¼ inch, 5.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 11.8 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 20.4 per cent; through $\frac{1}{40}$ inch, 61.2 per cent. The briquets were identical in character with those made from Indiana No. 1 B (p. 125) and Indiana No. 6 B (p. 127).

	Test 229*.	Test 230*†.		Test 229*.	Test 230*†.
Details of manufacture:			Details of manufacture—Con.		
Machine used	Eng.	Renf.	Heat value per pound—Con.		
Temperature of briquets, °F	176	140	Binder B. t. u.	16,864	16,864
Binder—			Drop test (1-inch screen):		
Kind	w. g. p.	w. g. p.	Held per cent	81.6	50.0
Laboratory No. (see p. 40)	4806	4806	Passed do	18.4	50.0
Amount per cent	7	9	Tumbler test (1-inch screen):		
Weight of—			Held per cent	79.3	81.5
Fuel briquetted, pounds	24,000	30,000	Passed (fines) do	20.7	18.5
Briquets, average, pounds	3.69	0.424	Fines through 10-mesh sieve per cent	72.5	92.3
Heat value per pound—			Water absorption:		
Fuel as received, B. t. u.	10,822	10,822	In 13 days do	7.4	.....
Fuel as fired. B. t. u.	11,945	12,046	In 23 days do	.....	13.8
			Average for first 5 days, per cent	1.20	1.86
			Specific gravity (apparent)	1.078	1.097

Extraction analyses.

	Pitch.	Fuel.	Briquets.	
			Test 229*.	Test 230*†.
Laboratory No.	4806	4708	4822	.....
Air-drying loss per cent	.....	10.00	.....	.....
Extracted by CS_2:				
Air-dried do	.....	1.46	.....	.....
As received do	96.90	1.31	6.87	8.50
Pitch in briquets, as received do	.....	.....	5.82	7.52

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, *pp. 100–102.*

INDIANA NO. 6.[a]

Bituminous screenings (through 1¼-inch bar screen) from vein No. 4 at Hymera, Sullivan County, on the Evansville and Terre Haute Railroad, were designated Indiana No. 6 B, shipped uninspected, and used in briquetting tests 220* and 227†.

CHEMICAL ANALYSES.

Indiana No. 6 B.

	Briquetting tests.[a]			Briquetting tests.[a]	
	220*.	227†.		220*.	227†.
Proximate:			Ultimate:		
Moisture	5.84	5.72	Hydrogen	5.04	4.76
Volatile matter	38.08	37.83	Carbon	70.61	66.48
Fixed carbon	44.22	43.16	Nitrogen	1.14	1.07
Ash	11.86	13.29	Oxygen	5.85	8.42
Sulphur	4.49	4.87	Ash	12.59	14.10
			Sulphur	4.77	5.17

[a] Proximate analysis of fuel as received; ultimate analysis on dry basis.

BRIQUETTING TESTS.

Indiana No. 6 B (screenings).

Tests 220, 227†.*—Size as used: Over ¼-inch, 1.2 per cent; $\frac{1}{16}$-inch to ¼-inch, 5.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 10.2 per cent; $\frac{1}{16}$ inch to $\frac{1}{20}$ inch, 20.4 per cent; through $\frac{1}{40}$ inch, 62.6 per cent. Renfrow briquets were similar to those made from Indiana 1 B coal. Seven per cent binder gave satisfactory English briquets when coal was thoroughly dried; otherwise briquets were soft and easily broken when cold. Briquets were soft and spongy when warm, although cohesive enough to be handled without breaking. When cold they became tough with porous surfaces, rough fractures, and ragged edges.

	Test 220*.	Test 227†.		Test 220*.	Test 227†.
Details of manufacture:			Details of manufacture—Con.		
Machine used	Renf.	Eng.	Heat value per pound—Con.		
Temperature of briquets, °F	140	168	Binder ... B. t. u.	16,864	16,864
Binder—			Drop test (1-inch screen):		
Kind	w. g. p.	w. g. p.	Held ... per cent	58.5	83.7
Laboratory No. (see p. 40)	4806	4806	Passed ... per cent	41.5	16.3
Amount ... per cent	8.5	7	Tumbler test (1-inch screen):		
Weight of—			Held ... per cent	84.0	81.2
Fuel briquetted, pounds	64,000	8,000	Passed (fines) ... do	16.0	18.8
Briquets, average, pounds	0.484	3.84	Fines through 10-mesh sieve ... per cent	90.0	78.3
Heat value per pound—			Water absorption:		
Fuel as received, B. t. u.	10,987	10,987	In 13 days ... do	12.5	6.7
Fuel as fired. B. t. u.	12,132	11,839	Average for first 5 days, per cent	2.04	1.06
			Specific gravity (apparent)	1.083	1.156

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 102-105.

Extraction analyses.

	Pitch.	Fuel.	Briquets.	
			Test 220*.	Test 227†.
Laboratory No.	4806	4604	4835	4872
Air-drying loss ... per cent	.....	7.00	3.30	2.70
Extracted by CS_2:				
Air-dried ... do	.....	.82	8.38	7.68
As received ... do	96.90	.76	8.10	7.47
Pitch in briquets, as received ... do	.....	.....	7.64	6.99

INDIANA NO. 12.

Bituminous coal from Hartwell, Pike County, on the Southern Railway, was designated Indiana No. 12. The coal, as worked from the outcrop at this place, averages 4 feet 10 inches in thickness.

This sample, shipped under the supervision of W. J. Von Borries, consisted of run-of-mine coal, and was used in making steaming tests 299, 300, and 310 (on washed coal); producer-gas test 99; washing test 145; coking tests 108 (raw), 109 (washed), and 110 (washed); and cupola test 121 (washed coal).

Two mine samples were taken for chemical analysis. Sample 2701 was taken 1,200 feet nothwest of the opening, where the coal measured 4 feet 9 inches in thickness. Sample 2702 was taken 900 feet northwest of the opening, where the coal measured 5 feet in thickness.

CHEMICAL ANALYSES.

Indiana No. 12.

	Mine samples.		Car samples.		Steaming tests.[a]		
					299.	300.	310.
Laboratory number	2701	2702	2759	2825	.....	.....	.....
Air-drying loss	8.20	8.50	6.40	11.00	.....	.....	.....
Proximate:							
Moisture	11.29	11.10	10.57	12.99	12.81	12.41	12.87
Volatile matter	38.35	37.11	35.03	34.27	33.48	34.12	35.85
Fixed carbon	43.49	43.27	42.75	40.55	39.63	39.61	43.34
Ash	6.87	8.52	11.65	12.19	14.08	13.86	7.94
Sulphur	3.09	3.86	3.87	3.97	3.84	4.21	3.02
Ultimate:							
Hydrogen	.....	.....	5.40	.....	4.54	4.54	5.00
Carbon	.....	.....	61.11	.....	65.66	65.61	72.27
Nitrogen	.....	.....	1.17	.....	1.26	1.26	1.39
Oxygen	.....	.....	16.80	.....	7.99	7.96	8.76
Ash	.....	.....	.....	.....	16.15	15.82	9.11
Sulphur	.....	.....	.....	.....	4.40	4.81	3.47
Calorific value (as received):							
Determined ... calories	6,623	.....	6,259	.....	.....	.....	.....
Determined ... B. t. u.	11,921	.....	11,266	.....	.....	.....	.....
Calculated from ultimate analysis ... calories	.....	.....	6,161	.....	.....	.....	.....
Calculated from ultimate analysis ... B. t. u.	.....	.....	11,090	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 12 (run of mine).

	Test 299.	Test 300.	Test 310 (w.).
Size as used:			
Over 1 inch ... per cent	27.5	30.5	28.9
½ inch to 1 inch ... do	21.8	24.3	24.8
¼ inch to ½ inch ... do	18.3	18.9	23.6
Under ¼ inch ... do	32.4	26.3	22.7
Duration of test ... hours	10.08	10.05	9.48
Kind of grate	Rocking.	Rocking.	.....
Heating value of coal ... B. t. u. per pound dry coal	12,116	12,130	13,271
Force of draft:			
Under stack damper ... inch water	0.50	0.54	0.49
Above fire ... do	.16	.19	.11
Furnace temperature ... °F	2,359	2,397	2,722
Dry coal used per square foot of grate surface per hour ... pounds	22.99	25.13	19.04
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.32	3.71	3.49
Percentage of rated horsepower of boiler developed	93.1	103.9	97.8
Water apparently evaporated per pound of coal as fired ... pounds	5.85	5.99	6.69
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	7.02	7.20	8.00
Per pound of dry coal ... do	8.05	8.22	9.18
Per pound of combustible ... do	9.78	10.02	10.29
Efficiency of boiler, including grate ... per cent	64.16	65.44	66.80
Coal as fired:			
Per indicated horsepower hour ... pounds	4.03	3.93	3.53
Per electrical horsepower hour ... do	4.97	4.85	4.36
Dry coal:			
Per indicated horsepower hour ... do	3.51	3.44	3.08
Per electrical horsepower hour ... do	4.34	4.25	3.80

PRODUCER-GAS TEST.

Indiana No. 12 (run of mine).

Test 99.—Size as used: Over 1 inch, 47 per cent; ½ inch to 1 inch, 23 per cent; ¼ inch to ½ inch, 12 per cent; under ¼ inch, 18 per cent. Duration of test, 50 hours; average electrical horsepower, 194.4; average B. t. u. per cubic foot of gas, 149.4; total coal fired, 17,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.86	1.66	1.43
Developed at switch board	1.77	1.59	1.36
Per brake horsepower:			
Commercially available	1.58	1.41	1.22
Developed at engine	1.50	1.35	1.16
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.97	1.76	1.52
Developed at switch board	1.87	1.68	1.44
Per brake horsepower:			
Commercially available	1.67	1.50	1.29
Developed at engine	1.59	1.43	1.23

Analyses.

Coal.		*Gas by volume.*	
Moisture	10.42	Carbon dioxide (CO_2)	9.0
Volatile matter	36.29	Carbon monoxide (CO)	19.0
Fixed carbon	40.75	Hydrogen (H_2)	13.0
Ash	12.54	Methane (CH_4)	2.0
Sulphur	3.96	Nitrogen (N_2)	56.0
		Ethylene (C_2H_4)	1.0

WASHING AND COKING TESTS.

Indiana No. 12 (run of mine).

Washing test 145.—Size as used, crushed to 2-inch. Jig used, Stewart. Raw coal, 40,000 pounds; washed coal, 35,060 pounds; refuse, 4,940 pounds.

Coking tests.

		Test 108 (raw).	Test 109 (w.).	Test 110 (w.).
Size as used		f. c.	f. c.	r. o. m.
Duration of test	hours	37	35	44
Coal charged	pounds	10,000	10,000	12,000
Coke produced	do	5,258	5,304	6,355
	per cent	52.58	53.04	52.96
Breeze produced	pounds	464	255	296
	per cent	4.64	2.55	2.47
Total yield	do	57.22	55.59	55.43

Remarks.—Test 108: Light-gray color; some little silvery; breakage, good-sized pieces; cell structure rather large; high ash and sulphur Test 109: Light gray and silvery; better than coke from raw coal; breakage, good-sized pieces; cell structure rather large; good weight; sulphur not much reduced by washing. Test 110: Light gray and silvery; practically same as test 109; breakage little better, larger size; cell structure not quite so large; good weight coke; sulphur not materially reduced by washing.

Analyses.

	Washing test 145.		Coking test 108.		Coking test 109.		Coking test 110.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	10.57	14.16	11.77	0.88	13.79	0.60	12.82	0.42
Volatile matter	35.03	.....	33.78	0.62	35.43	1.15	37.25	1.03
Fixed carbon	42.75	.....	40.00	75.95	42.75	84.32	41.52	84.37
Ash	11.65	7.85	14.45	22.55	8.03	13.93	8.41	14.18
Sulphur	3.87	3.29	4.32	3.84	3.22	2.86	3.33	2.89

Cupola test of coke made from Indiana No. 12 coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Material.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
121	110	1.87	7	96.53	Coke	180	63	63	62	62	430
					Pig iron	540	428	428	427	427	2,250
					Scrap	180	143	143	142	142	750

[a] Sulphur in ash, 0.06 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
121	10.42 a. m.	7	12	1,752	199	1,951	25	4,682	5.48	6.57	852	74

Cupola test of coke made from Indiana No. 12 coal (washed)—Continued.

LADLE RECORD.

Ladle No.	Test 121.		Ladle No.	Test 121.	
	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).
1	80	10.57	12	76	11.09
2	77	10.58	13	106	11.10
3	110	10.59	14	100	11.10½
4	60	11.02	15	32	11.11
5	83	11.02½	16	102	11.13
6	58	11.03	17	96	11.13½
7	106	11.05	18	49	11.14
8	95	11.05½	19	24	11.15
9	57	11.06	20	27	11.16
10	99	11.08	21	94	11.18
11	95	11.08½	22	126	11.19

Remarks.—Test 121: Iron dull.

INDIANA NO. 13.

Bituminous coal from bed No. 6 at Terre Haute, Vigo County, on the Vandalia line, was designated Indiana No. 13. The coal, as worked at a depth of 65 feet at this place, averages 5 feet 3 inches in thickness.

One sample, shipped under the supervision of J. W. Groves, consisted of run-of-mine coal, which was used in steaming tests 432 and 433 and producer-gas tests 132 and 138.

Two mine samples were taken for chemical analysis. Sample 3467 was taken 3,000 feet south of the shaft, where the coal measured 4 feet 10½ inches in thickness. Sample 3468 was taken 3,000 feet southwest of the shaft, where the coal measured 5 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Indiana No. 13.

	Mine samples.		Car sample.	Steaming tests.[a]	
				432.	433.
Laboratory No.	3467	3468	3748		
Air-drying loss	8.00	8.30	5.60		
Proximate:					
Moisture	13.43	13.88	12.97	12.79	13.58
Volatile matter	36.72	35.89	37.45	35.45	33.93
Fixed carbon	42.51	41.54	39.67	39.67	40.81
Ash	7.34	8.69	12.09	12.09	11.68
Sulphur	2.16	3.26	3.18	3.18	2.92
Ultimate:					
Hydrogen			5.58	4.77	4.80
Carbon			59.84	68.61	69.13
Nitrogen			.82	.94	.95
Oxygen			18.49	8.17	8.22
Ash				13.86	13.52
Sulphur				3.65	3.38
Calorific value determined (as received) calories	6,360		6,055		
Calorific value determined (as received) B. t. u.	11,448		10,899		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 13.

		Test 432.	Test 433.
Size as used:			
Over 1 inch	per cent	46.5	.....
½ inch to 1 inch	do	21.1	.....
¼ inch to ½ inch	do	12.7	.....
Under ¼ inch	do	19.7	.....
Average diameter	inches	1.33	.....
Duration of test	hours	10.08	3.75
Heating value of coal	B. t. u. per pound dry coal	12,497	12,577
Force of draft:			
Under stack damper	inch water	0.69	0.74
Above fire	do	.13	.16
Furnace temperature	° F.	2,290	2,260
Dry coal used per square foot of grate surface per hour	pounds	19.90	20.52
Equivalent water evaporated per square foot of water-heating surface per hour, pounds		3.42	3.29
Percentage of rated horsepower of boiler developed		95.8	92.1
Water apparently evaporated per pound of coal as fired	pounds	6.45	5.97
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	7.50	6.93
Per pound of dry coal	do	8.60	8.02
Per pound of combustible	do	10.23	9.70
Efficiency of boiler, including grate	per cent	66.46	61.58
Coal as fired:			
Per indicated horsepower hour	pounds	3.77	4.08
Per electrical horsepower hour	do	4.65	5.04
Dry coal:			
Per indicated horsepower hour	do	3.29	3.53
Per electrical horsepower hour	do	4.06	4.35

PRODUCER-GAS TESTS.

Indiana No. 13 (run of mine).

		Test 132.	Test 138.
Size as used:			
Over 1 inch	per cent	36	54
½ inch to 1 inch	do	24	26
¼ inch to ½ inch	do	16	12
Under ¼ inch	do	24	8
Duration of test	hours	50	24
Average electrical horsepower		160.0	189.8
Average B. t. u. per cubic foot of gas		131.9	178.0
Total coal fired	pounds	15,300	6,750

	Test 132.			Test 138.		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	2.02	1.79	1.52	1.55	1.38	1.21
Developed at switchboard	1.91	1.69	1.44	1.48	1.32	1.16
Per brake horsepower:						
Commercially available	1.72	1.52	1.30	1.32	1.18	1.03
Developed at engine	1.63	1.44	1.23	1.26	1.13	0.99
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	2.21	1.95	1.66	1.68	1.50	1.32
Developed at switchboard	2.09	1.85	1.57	1.61	1.44	1.46
Per brake horsepower:						
Commercially available	1.88	1.66	1.41	1.43	1.27	1.12
Developed at engine	1.77	1.57	1.33	1.39	1.22	1.07

Analyses.

	Test 132.	Test 138.		Test 132.	Test 138.
Coal.			*Gas by volume.*		
Moisture	11.53	10.70	Carbon dioxide (CO_2)	12.5	10.9
Volatile matter	34.80	35.58	Carbon monoxide (CO)	14.9	18.0
Fixed carbon	40.44	42.85	Hydrogen (H_2)	12.8	15.2
Ash	13.23	10.87	Methane (CH_4)	1.9	1.9
Sulphur	3.11	3.06	Nitrogen (N_2)	57.5	53.6
			Oxygen (O_2)	.0	.0
			Ethylene (C_2H_4)	.4	.4

INDIANA NO. 14.

Bituminous coal from bed No. 3 at Seelyville, Vigo County, on the Vandalia line, was designated Indiana No. 14. The coal, as worked at a depth of 90 feet at this place, averages 7 feet 5 inches in thickness.

One sample, consisting of run-of-mine coal, shipped under the supervision of F. B. Tough, was used in steaming tests 430 and 431 and producer-gas test 131.

Two mine samples were taken for chemical analysis. Sample 3491 was taken 2,400 feet northeast of the shaft, where the coal measured 7 feet 5¼ inches in thickness. Sample 3492 was taken 900 feet southeast of the shaft, where the coal measured 7 feet 6¼ inches in thickness.

CHEMICAL ANALYSES.

Indiana No. 14.

	Mine samples.		Car sample.	Steaming tests.[a]	
				430.	431.
Laboratory No	3491	3492	3775	.....	.....
Air-drying loss	8.70	7.00	3.70	.....	.....
Proximate:					
Moisture	13.62	11.46	7.88	8.52	9.39
Volatile matter	38.21	37.45	36.85	35.99	33.58
Fixed carbon	41.06	40.39	41.07	41.10	36.89
Ash	7.11	10.70	14.20	14.39	20.14
Sulphur	3.28	5.45	5.14	5.62	5.47
Ultimate:					
Hydrogen	.....	.....	5.22	4.66	4.28
Carbon	.....	.....	59.75	64.15	58.90
Nitrogen	.....	.....	.93	1.00	.92
Oxygen	.....	.....	14.76	8.32	7.63
Ash	.....	.....	.....	15.73	22.23
Sulphur	.....	.....	.....	6.14	6.04
Calorific value determined (as received) calories	6,413	.....	6,192	.....	.....
Calorific value determined (as received) B. t. u.	11,543	.....	11,146	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 14 (run of mine).

		Test 430.	Test 431.
Size as used:			
Over 1 inch	per cent	67.3	36.9
½ inch to 1 inch	do	15.4	18.7
¼ inch to ½ inch	do	8.0	14.2
Under ¼ inch	do	9.3	30.2
Average diameter	inches	1.68	1.13
Duration of test		9.92	10.00
Heating value of coal	B. t. u. per pound dry coal	11,986	11,021
Force of draft:			
Under stack damper	inch water	0.69	0.68
Above fire	do	.18	.16
Dry coal used per square foot of grate surface per hour	pounds	18.89	19.31
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	3.03	3.02
Percentage of rated horsepower of boiler developed		84.9	84.6
Water apparently eveporated per pound of coal as fired	pounds	6.30	6.10
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	7.35	7.09
Per pound of dry coal	do	8.03	7.83
Per pound of combustible	do	9.80	10.42
Efficiency of boiler, including grate	per cent	64.70	68.61
Coal as fired:			
Per indicated horsepower hour	pounds	3.85	3.99
Per electrical horsepower hour	do	4.75	4.92
Dry coal:			
Per indicated horsepower hour	do	3.52	3.61
Per electrical horsepower hour	do	4.35	4.46

PRODUCER-GAS TEST.

Indiana No. 14 (run of mine).

Test 131.—Size as used, over 1 inch, 50 per cent; ½ inch to 1 inch, 26 per cent; ¼ inch to ½ inch, 12 per cent; under ¼ inch, 12 per cent. Duration of test, 50 hours. Average electrical horsepower, 189.8. Average B. t. u. per cubic foot of gas, 154.1. Total coal fired, 16,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.80	1.66	1.40
Developed at switchboard	1.71	1.57	1.33
Per brake horsepower:			
Commercially available	1.53	1.41	1.19
Developed at engine	1.45	1.34	1.13
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.91	1.76	1.49
Developed at switchboard	1.81	1.67	1.41
Per brake horsepower:			
Commercially available	1.62	1.49	1.26
Developed at engine	1.54	1.42	1.20

Analyses.

Coal.		*Gas by volume.*	
Moisture	7.88	Carbon dioxide (CO_2)	9.8
Volatile matter	36.85	Carbon monoxide (CO)	20.4
Fixed carbon	41.07	Hydrogen (H_2)	14.4
Ash	14.20	Methane (CH_4)	2.2
Sulphur	5.14	Nitrogen (N_2)	52.7
		Ethylene (C_2H_4)	.5

INDIANA NO. 15.

Bituminous coal from bed No. 4 at Linton, Greene County, on the Southern Indiana Railroad, was designated Indiana No. 15. The coal, as worked at a depth of 90 feet at this place, averages 4 feet 4 inches in thickness.

One sample, shipped under the supervision of F. B. Tough, consisted of run-of-mine coal, and was used in steaming tests 428 and 429 and producer-gas tests 134 and 137.

Two mine samples were taken for chemical analysis. Sample 3473 was taken 2,000 feet southeast of the shaft, where the coal measured 4 feet 7 inches in thickness. Sample 3474 was taken 1,900 feet northeast of the shaft, where the coal measured 4 feet 1 inch in thickness.

CHEMICAL ANALYSES.

Indiana No. 15.

	Mine samples.		Car sample.	Steaming tests.[a]	
				428.	429.
Laboratory No	3473	3474	3567	.....	.....
Air-drying loss	5.10	7.80	9.10	.....	.....
Proximate:					
Moisture	13.53	13.98	13.58	13.05	12.83
Volatile matter	33.54	32.57	32.07	31.34	32.49
Fixed carbon	45.38	46.35	46.20	46.78	46.45
Ash	7.55	7.10	8.15	8.83	8.23
Sulphur	.95	.96	.91	.99	.97
Ultimate:					
Hydrogen	.....	.....	5.65	4.75	4.78
Carbon	.....	.....	63.53	72.85	73.45
Nitrogen	.....	.....	1.42	1.63	1.64
Oxygen	.....	.....	20.34	9.47	9.58
Ash	.....	.....	.....	10.16	9.44
Sulphur	.....	.....	.....	1.14	1.11
Calorific value determined (as received) .. calories	6,521	.....	6,344	.....	.....
Calorific value determined (as received) .. B. t. u.	11,738	.....	11,419	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car samples.

STEAMING TESTS.

Indiana No. 15 (run of mine).

	Test 428.	Test 429.
Size as used:		
Over 1 inch ..... per cent	44.6	33.9
½ inch to 1 inch ..... do	21.2	19.5
¼ inch to ½ inch ..... do	12.1	13.4
Under ¼-inch ..... do	22.1	33.2
Average diameter ..... inches	1.03	.85
Duration of test ..... hours	9.7	10.05
Heating value of coal ..... B. t. u. per pound dry coal	13,099	13,207
Force of draft:		
Under stack damper ..... inch water	0.76	0.73
Above fire ..... do	.14	.13
Dry coal used per square foot of grate surface per hour ..... pounds	20.12	18.27
Equivalent water evaporated per square foot of water-heating surface per hour ..... pounds	3.41	3.13
Percentage of rated horsepower of boiler developed	95.6	87.9
Water apparently evaporated per pound of coal as fired ..... pounds	6.34	6.43
Water evaporated from and at 212° F.:		
Per pound of coal as fired ..... do	7.39	7.49
Per pound of dry coal ..... do	8.50	8.59
Per pound of combustible ..... do	9.71	9.73
Efficiency of boiler, including grate ..... per cent	62.66	62.81
Coal as fired:		
Per indicated horsepower hour ..... pounds	3.83	3.78
Per electrical horsepower hour ..... do	4.72	4.66
Dry coal:		
Per indicated horsepower hour ..... do	3.33	3.29
Per electrical horsepower hour ..... do	4.11	4.06

		Test 134.	Test 137.
Size as used:			
Over 1 inch	per cent	53	48
½ inch to 1 inch	do	19	20
¼ inch to ½ inch	do	12	11
Under ¼ inch	do	16	21
Duration of test	hours	50	50
Average electrical horsepower		189.7	193.8
Average B. t. u. per cubic foot of gas		144.1	145.7
Total coal fired	pounds	14,650	14,050

	Test 134.			Test 137.		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	1.63	1.44	1.30	1.53	1.35	1.22
Developed at switchboard	1.55	1.37	1.24	1.45	1.29	1.16
Per brake horsepower:						
Commercially available	1.38	1.23	1.11	1.30	1.15	1.04
Developed at engine	1.31	1.16	1.05	1.23	1.09	0.99
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	1.75	1.55	1.39	1.65	1.46	1.32
Developed at switchboard	1.66	1.47	1.32	1.56	1.38	1.25
Per brake horsepower:						
Commercially available	1.48	1.32	1.16	1.40	1.24	1.12
Developed at engine	1.41	1.25	1.12	1.33	1.18	1.06

Analyses.

	Tests 134 and 137.		Test 134.	Test 137.
Coal.		*Gas by volume.*		
Moisture	11.42	Carbon dioxide (CO_2)	11.2	10.6
Volatile matter	34.11	Carbon monoxide (CO)	17.2	18.3
Fixed carbon	45.82	Hydrogen (H_2)	15.2	14.9
Ash	8.65	Methane (CH_4)	2.2	2.0
Sulphur	1.03	Nitrogen (N_2)	53.8	53.8
		Ethylene (C_2H_4)	.4	.4

INDIANA NO. 16.

Bituminous coal from bed No. 5, at Linton, Greene County, on the Vandalia line, was designated Indiana No. 16. The coal, as worked at a depth of 95 feet at this place, averages 7 feet 2 inches in thickness.

One sample, shipped under the supervision of J. W. Groves, consisted of run-of-mine coal, which was used in steaming tests 426 and 427 and producer-gas test 130.

Two mine samples were taken for chemical analysis. Sample 3475 was taken 650 feet west of the shaft, where the coal measured 7 feet 4 inches in thickness. Sample 3476 was taken 500 feet southeast of the shaft, where the coal measured 7 feet in thickness.

CHEMICAL ANALYSES.

Indiana No. 16.

	Mine samples.		Car sample.	Steaming tests.[a]	
				426.	427.
Laboratory No	3475	3476	3564		
Air-drying loss	6.00	8.60	5.90		
Proximate:					
Moisture	10.91	11.51	10.30	9.09	10.09
Volatile matter	37.86	36.78	36.31	35.20	33.62
Fixed carbon	42.02	40.49	41.64	43.21	43.51
Ash	9.21	11.22	11.75	12.50	12.78
Sulphur	3.16	4.17	4.23	4.77	4.34
Ultimate:					
Hydrogen			5.38	4.66	4.66
Carbon			61.00	67.02	66.99
Nitrogen			1.06	1.17	1.17
Oxygen			16.58	8.15	8.14
Ash				13.75	14.21
Sulphur				5.25	4.83
Calorific value determined (as received) calories			6,232		
Calorific value determined (as received) B. t. u.			11,218		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 16 (run of mine).

	Test 426.	Test 427.
Size as used:		
Over 1 inch ... per cent	38.0	27.1
½ inch to 1 inch ... do	21.8	25.3
¼ inch to ½ inch ... do	14.0	17.0
Under ¼ inch ... do	26.2	30.6
Average diameter ... inch	0.86	0.76
Duration of test ... hours	10.03	9.0
Heating value of coal ... B. t. u. per pound dry coal	12,350	12,328
Force of draft:		
Under stack damper ... inch water	0.69	0.67
Above fire ... do	.13	.15
Dry coal used per square foot of grate surface per hour ... pounds	19.26	17.24
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.18	2.80
Percentage of rated horsepower of boiler developed	89.1	78.6
Water apparently evaporated per pound of coal as fired ... pounds	6.47	6.30
Water evaporated from and at 212° F.:		
Per pound of coal as fired ... do	7.51	7.32
Per pound of dry coal ... do	8.26	8.14
Per pound of combustible ... do	9.83	9.72
Efficiency of boiler, including grate ... per cent	64.59	63.76
Coal as fired:		
Per indicated horsepower hour ... pounds	3.77	3.86
Per electrical horsepower hour ... do	4.65	4.77
Dry coal:		
Per indicated horsepower hour ... do	3.42	3.47
Per electrical horsepower hour ... do	4.23	4.29

PRODUCER-GAS TEST.

Indiana No. 16 (run of mine).

Test 130.—Duration of test, 50 hours. Average electrical horsepower, 177.4. Average B. t. u. per cubic foot of gas, 136.7. Total coal fired, 16,100 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.92	1.77	1.54
Developed at switchboard	1.82	1.68	1.46
Per brake horsepower:			
Commercially available	1.63	1.51	1.31
Developed at engine	1.54	1.42	1.24

PRODUCER-GAS TEST—Continued.

Indiana No. 16 (run of mine).

	Coal as fired.	Dry coal.	Combustible.
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.06	1.90	1.66
Developed at switchboard	1.95	1.80	1.57
Per brake horsepower:			
Commercially available	1.75	1.62	1.41
Developed at engine	1.66	1.53	1.33

Analyses.

Coal.		*Gas by volume.*	
Moisture	7.79	Carbon dioxide (CO_2)	11.4
Volatile matter	32.32	Carbon monoxide (CO)	16.8
Fixed carbon	44.97	Hydrogen (H_2)	13.3
Ash	11.92	Methane (CH_4)	1.7
Sulphur	4.01	Nitrogen (N_2)	56.3
		Ethylene (C_2H_4)	.5

INDIANA NO. 17.

Bituminous coal from bed No. 5 at Bicknell, Knox County, on the Vandalia line, was designated Indiana No. 17. The coal, as worked at a depth of 190 feet at this place, averages 5 feet 6 inches in thickness.

One sample, shipped under the supervision of J. W. Groves, consisted of run-of-mine coal and was used in steaming tests 441 and 442, coking test 163, and cupola test 148.

Two mine samples were taken for chemical analysis. Sample 3516 was taken 500 feet northeast of the shaft, where the coal measured 5 feet 2 inches in thickness. Sample 3517 was taken 250 feet northwest of the shaft, where the coal measured 5 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Indiana No. 17.

	Mine samples.		Car. sample.	Steaming tests.[a]	
				441.	442.
Laboratory No	3516	3517	3981		
Air-drying loss	6.10	6.90	5.10		
Proximate:					
Moisture	10.60	11.87	12.08	9.70	12.08
Volatile matter	38.06	36.23	32.48	35.78	32.48
Fixed carbon	43.04	43.84	44.42	45.63	44.42
Ash	8.30	8.06	11.02	8.89	11.02
Sulphur	3.69	4.05	3.65	3.67	3.65
Ultimate:					
Hydrogen			5.34	4.70	4.55
Carbon			60.45	71.05	68.75
Nitrogen			.89	1.04	1.01
Oxygen			18.65	9.30	9.00
Ash				9.85	12.54
Sulphur				4.06	4.15
Calorific value determined (as received) calories	6,529		6,117		
Calorific value determined (as received) B. t. u.	11,752		11,011		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 17 (run of mine).

	Test 441.	Test 442.
Size as used:		
Over 1 inch ... per cent	47.3	16.8
½ inch to 1 inch ... do	26.9	22.7
¼ inch to ½ inch ... do	13.6	18.0
Under ¼ inch ... do	12.2	42.5
Average diameter ... inches	1.20	0.60
Duration of test ... hours	9.88	10.13
Heating value of coal ... B. t. u. per pound dry coal	12,929	12,524
Force of draft:		
Under stack damper ... inch water	0.75	0.74
Above fire ... do	.13	.15
Furnace temperature ... °F	2,545	2,544
Dry coal used per square foot of grate surface per hour ... pounds	19.61	17.98
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.23	2.79
Percentage of rated horsepower of boiler developed	90.7	78.2
Water apparently evaporated per pound of coal as fired ... pounds	6.41	5.85
Water evaporated from and at 212 °F.:		
Per pound of coal as fired ... pounds	7.46	6.83
Per pound of dry coal ... do	8.26	7.77
Per pound of combustible ... do	9.53	9.35
Efficiency of boiler, including grate ... per cent	61.70	59.91
Coal as fired:		
Per indicated horsepower hour ... pounds	3.70	4.14
Per electrical horsepower hour ... do	4.68	5.11
Dry coal:		
Per indicated horsepower hour ... do	3.42	3.64
Per electrical horsepower hour ... do	4.23	4.49

COKING TEST.

Indiana No. 17 (run of mine).

Test 163.—Size as used, washed, finely crushed. Duration of test, 50 hours. Coal charged, 12,050 pounds. Coke produced, 7,200 pounds; 59.75 per cent. Breeze produced, 332 pounds; 2.76 per cent. Total yield, 62.51 per cent. Dark-gray color; poor, dense coke; ash and sulphur high.

Analyses.

	Coal.	Coke.
Moisture	10.57	1.65
Volatile matter	35.65	.67
Fixed carbon	43.77	81.42
Ash	10.01	16.26
Sulphur	3.76	3.39

Cupola test of coke made from Indiana No. 17 coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
148	163	1.92	7	94.44	Coke	190	60	60	60	60	430
					Pig iron	760	560	560	560	560	3,000

Cupola test of coke made from Indiana No. 17 coal (washed)—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
148	11.17 a. m...	7	11	1,548	274	1,822	32	3,416	4.82	4.50	1,043	52

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (pounds).	Silicon.		Manganese.		Sulphur.		Content of coke combined with iron melted (per cent).
			Per cent.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	
148	Pig iron	.....	2.12	38.63	0.178	3.243	0.059	1.0750	6.88
	Melted iron:								
	Amount	.....	1.75	31.88	.126	2.296	.108	1.9678	
	Gain or loss	.....	−17.47	−6.75	−29.20	−.947	+.049	+.8928	
	Coke	383	.....	.....	.....	.....	3.39	12.9837	

LADLE RECORD.

Ladle No.	Pounds.	Time (a. m.).	Ladle No.	Pounds.	Time (a.m.).
1	24	11.30	11	96	11.47
2	95	11.34	12	80	11.49
3	101	11.34½	13	73	11.49½
4	79	11.39	14	96	11.50
5	94	11.39½	15	65	11.54
6	108	11.40	16	68	11.54½
7	76	11.41	17	85	11.55
8	98	11.42	18	56	11.59
9	78	11.46	19	108	12.00
10	68	11.46½			

Remarks.—Pig iron used from car 27633. Temperature of iron, medium.

INDIANA NO. 18.

Bituminous coal from bed No. 5 at Ayrshire, Pike County, on the Southern Railway, was designated Indiana No. 18. The coal, as worked from the outcrop at this place, averages 4 feet 9 inches in thickness.

Two samples were shipped under the supervision of John W. Groves, as follows: Indiana No. 18 A consisted of washed slack screened through a ⅞-inch wire-mesh revolving screen, and was used in coking tests 158 and 168. Indiana No. 18 B consisted of lump coal over a 1¾-inch round shaking screen, and was used in steaming tests 435 and 436 and producer-gas tests 133 and 135.

Two mine samples were taken for chemical analysis. Sample 3525 was taken 3,400 feet south of the opening, where the coal

measured 4 feet 9 inches in thickness. Sample 3526 was taken 3,400 feet southwest of the opening, where the coal measured 4 feet 10 inches in thickness.

CHEMICAL ANALYSES.

Indiana No. 18.

	Mine samples.		Car sample (B).	Steaming tests.[a]	
				435.	436.
Laboratory No	3525	3526	3801		
Air-drying loss	5.30	7.40	3.10		
Proximate:					
Moisture	12.88	13.83	11.13	12.04	12.09
Volatile matter	34.71	34.24	35.11	34.09	34.10
Fixed carbon	46.27	45.91	46.78	46.84	47.03
Ash	6.14	6.02	6.98	7.03	6.78
Sulphur	1.70	1.41	1.64	1.65	1.37
Ultimate:					
Hydrogen			5.65	4.92	4.96
Carbon			66.94	74.22	74.72
Nitrogen			1.34	1.30	1.30
Oxygen			17.45	9.69	9.75
Ash				7.99	7.71
Sulphur				1.88	1.56
Calorific value determined (as received) calories	6,556		6,684		
Calorific value determined (as received) B. t. u.	11,801		12,031		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indiana No. 18 B (lump).

		Test 435.	Test 436.
Size as used:			
Over 1 inch	per cent	30.4	45.1
½ inch to 1 inch	do	17.4	23.5
¼ inch to ½ inch	do	21.8	12.8
Under ¼ inch	do	30.4	18.6
Average diameter inch		0.77	0.97
Duration of test	hours	10.1	9.67
Heating value of coal	B. t. u. per pound dry coal	13,545	13,617
Force of draft:			
Under stack damper	inch water	0.64	0.73
Above fire	do	.05	.07
Dry coal used per square foot of grate surface per hour	pounds	20.47	21.85
Equivalent water evaporated per square foot of water-heating surface per hour, pounds		3.62	3.91
Percentage of rated horsepower of boiler developed		101.4	109.7
Water apparently evaporated per pound of coal as fired	pounds	6.70	6.76
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	7.79	7.89
Per pound of dry coal	do	8.85	8.97
Per pound of combustible	do	9.86	10.05
Efficiency of boiler, including grate	per cent	63.10	63.61
Coal as fired:			
Per indicated horsepower hour	pounds	3.63	3.58
Per electrical horsepower hour	do	4.48	4.42
Dry coal:			
Per indicated horsepower hour	do	3.20	3.15
Per electrical horsepower hour	do	3.94	3.89

PRODUCER-GAS TESTS.

Indiana No. 18 B (lump).

		Test 135.	Test 133.
Size as used:			
Over 1 inch	per cent	65	62
½ inch to 1 inch	do	15	17
¼ inch to ½ inch	do	8	9
Under ¼ inch	do	12	12
Duration of test	hours	50	36
Average electrical horsepower		196.3	194.5
Average B. t. u. per cubic foot of gas		152.6	154.7
Total coal fired	pounds	16,350	10,350

	Test 135.			Test 133.		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	1.75	1.54	1.42	1.55	1.38	1.27
Developed at switchboard	1.67	1.46	1.35	1.48	1.31	1.21
Per brake horsepower:						
Commercially available	1.49	1.31	1.21	1.32	1.17	1.08
Developed at engine	1.42	1.24	1.15	1.26	1.12	1.03
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	1.88	1.65	1.52	1.67	1.48	1.37
Developed at switchboard	1.79	1.57	1.45	1.59	1.41	1.30
Per brake horsepower:						
Commercially available	1.60	1.40	1.29	1.42	1.26	1.16
Developed at engine	1.52	1.34	1.23	1.35	1.20	1.11

Analyses.

	Test 135.	Test 133.		Test 135.	Test 133.
Coal.			*Gas by volume.*		
Moisture	12.11	11.13	Carbon dioxide (CO_2)	10.8	10.0
Volatile matter	34.19	35.11	Carbon monoxide (CO)	18.6	19.4
Fixed carbon	46.87	46.78	Hydrogen (H_2)	16.9	16.0
Ash	6.83	6.98	Methane (CH_4)	2.1	2.1
Sulphur	1.44	1.64	Nitrogen (N_2)	51.3	52.2
			Ethylene (C_2H_4)	.....	.3

COKING TESTS.

Indiana No. 18 A (washed slack).

	Test 158.	Test 168.
Size as used	not cr.	f. c.
Duration of test	hours 16	24
Coal charged	pounds 11,800	12,740
Coke produced	None.	None.

Remarks.—Test 158: Charge ashed down about 2 inches and blaze lost. Test 168: Charge ashed down about 3 inches and blaze lost.

Coking analyses of coal.

	Test 158.	Test 168.
Moisture	15.09	13.97
Volatile matter	31.06	30.97
Fixed carbon	46.42	48.07
Ash	7.43	6.99
Sulphur	1.48	1.49

INDIANA NO. 19.

Bituminous coal from the "Brazil Block top bed," at Diamond, Parke County, on the Chicago and Eastern Illinois Railroad, was designated Indiana No. 19. The coal, as worked at a depth of 121 feet at this place, averages 4 feet 4 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of screenings (through 1¼-inch stationary bar screen), and was used in steaming test 464 (on briquets) and briquetting test 165*.

Two mine samples were taken for chemical analysis. Sample 3534 was taken 1,200 feet southwest of the shaft, where the coal measured 4 feet 9 inches in thickness. Sample 3535 was taken 500 feet east of the shaft, where the coal measured 4 feet 1 inch in thickness.

CHEMICAL ANALYSES.

Indiana No. 19.

	Mine samples.		Steaming test 464.[a]	Briquetting test 165*.[b]
Laboratory No.	3534	3535	.....	4315
Air-drying loss	6.70	8.90	.....	.....
Air-dried sample:				
Proximate—				
Moisture	13.70	13.93	9.09	4.89
Volatile matter	35.94	35.18	34.61	30.53
Fixed carbon	44.45	45.82	40.70	44.00
Ash	5.91	5.07	15.60	20.58
Sulphur	2.66	1.93	3.04	3.36
Ultimate—				
Hydrogen	.....	.....	4.34	4.18
Carbon	.....	.....	63.67	61.71
Nitrogen	.....	.....	1.13	1.00
Oxygen	.....	.....	10.36	7.94
Ash	.....	.....	17.16	21.64
Sulphur	.....	.....	3.34	3.53
Calorific value determined (as received) calories	6,628	.....	.....	.....
Calorific value determined (as received) B. t. u.	11,930	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TEST.

Indiana No. 19 (Renfrow briquets).

	Test 464.
Duration of test ... hours	7.57
Heating value of fuel ... B. t. u. per pound dry fuel	11,930
Force of draft:	
Under stack damper ... inch water	0.79
Above fire ... do	.16
Furnace temperature ... °F.	2,613
Dry fuel used per square foot of grate surface per hour ... pounds	20.86
Equivalent water evaporated per square foot of water-heating surface per hour ... do	3.28
Percentage of rated horsepower of boiler developed	91.8
Water apparently evaporated per pound of fuel as fired ... pounds	5.92
Water evaporated from and at 212° F.:	
Per pound of fuel as fired ... do	7.15
Per pound of dry fuel ... do	7.86
Per pound of combustible ... do	9.62
Efficiency of boiler, including grate ... per cent	63.62
Fuel as fired:	
Per indicated horsepower hour ... pounds	3.96
Per electrical horsepower hour ... do	4.88
Dry fuel:	
Per indicated horsepower hour ... do	3.60
Per electrical horsepower hour ... do	4.44

Remarks.—Test made on briquets from test 165*, which burned well with short flame, making 5.5 per cent of black smoke. Briquets broke enough in burning to allow small percentage of fine unconsumed fuel to pass through grate. Ash and clinker of dark-gray color, not sufficient to retard draft. Clinker was easily broken with hook, but stuck to burning fuel; 33 per cent clinker was formed.

BRIQUETTING TEST.

Indiana No. 19 (raw screenings).

*Test 165**.—Size as used: Over $\frac{1}{4}$ inch, 3.6 per cent; $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, 12.4 per cent; $\frac{1}{32}$ inch to $\frac{1}{16}$ inch, 20 per cent; $\frac{1}{40}$ inch to $\frac{1}{32}$ inch, 24 per cent; through $\frac{1}{40}$ inch, 40 per cent. When made with dry coal and 8 per cent binder briquets were hard, with firm surfaces and very rough fracture. With moist coal satisfactory briquets were made regardless of percentage of binder used. These briquets had a dull-gray color, due to the presence of a large amount of clay. For analyses of briquets see page 143.

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ... per cent	64.0
Temperature of briquets ... °F.	131	Passed ... do	36.0
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held ... do	89.0
Laboratory No. (see p. 40)	[a] 3962 4120	Passed (fines) ... do	11.0
Amount ... per cent	8	Fines through 10-mesh sieve ... do	91.5
Weight of—		Weathering test:	
Fuel briquetted ... pounds	80,000	Time exposed ... days	95
Briquets, average ... do	0.562	Condition	C.
Heat value per pound—		Water absorption:	
Fuel as received ... B. t. u.	9,524	In 16 days ... per cent	12.6
Fuel as fired ... do	10,710	Average for first 5 days ... do	1.90
Binder ... do	16,946	Specific gravity (apparent)	1.211

[a] Binder contained 6 parts No. 4120 and 1 part No. 3962.

Extraction analyses.

	Pitches.		Fuel.	Briquets test 165*.
Laboratory No	3962	4120	3979	4315
Air-drying loss ... per cent	.....	.....	13.10	5.40
Extracted by CS_2:				
Air-dried ... do	.....	.....	.97	7.81
As received ... do	77.79	97.70	1.12	7.39
Pitch in briquets, as received ... do	.....	.....	.....	6.90

INDIANA NO. 20.

Bituminous coal from the "Brazil Block bottom bed," at Brazil, Clay County, on the Chicago and Eastern Illinois Railroad, was designated Indiana No. 20. This coal, as worked at a depth of 148 feet at this place, averages 3 feet 7 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of screenings through a 1¼-inch bar screen, and was used in washing test 185 and briquetting test 169*.

Two mine samples were taken for chemical analysis. Sample 3536 was taken 800 feet southeast of the shaft, where the coal measured 3 feet 5 inches in thickness. Sample 3537 was taken 600 feet northwest of the shaft, where the coal measured 3 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Indiana No. 20.

	Mine samples.		Car sample.	Briquetting test 169*.[a]
Laboratory No	3536	3537	3979	4627
Air-drying loss	11.30	10.40	13.10	.....
Proximate:				
Moisture	15.38	15.91	16.91	9.67
Volatile matter	32.66	33.19	26.85	35.75
Fixed carbon	46.08	46.05	38.87	47.65
Ash	5.88	4.85	17.37	6.93
Sulphur	1.95	1.22	1.89	1.40
Ultimate:				
Hydrogen	.....	.....	5.48	5.06
Carbon	.....	.....	52.97	75.14
Nitrogen	.....	.....	1.01	1.25
Oxygen	.....	.....	21.28	9.33
Ash	.....	.....	.....	7.67
Sulphur	.....	.....	.....	1.55
Calorific value determined (as received) ... calories	6,489	.....	5,291	.....
Calorific value determined (as received) ... B. t. u	11,680	.....	9,524	.....

[a] Proximate analysis of fuel as received; ultimate analysis on dry basis.

WASHING TEST.

Indiana No. 20 (screenings).

Test 185.—Size as used, screenings. Jig used, Stewart. Raw coal, 60,000 pounds. Washed coal, 40,000 pounds; 67 per cent. Refuse, 20,000 pounds; 33 per cent. For analysis of raw coal used see above (car sample 3979). Washed-coal analysis: Moisture, 16.86; ash, 7.09; sulphur, 1.35.

BRIQUETTING TEST.

Indiana No. 20 (washed screenings).

*Test 169**.—Size as used: $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, 3.0 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 16.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 26.6 per cent; through $\frac{1}{40}$ inch, 54.2 per cent. Briquets satisfactory when made warm, using 7 per cent binder; surface became soft and easily abraded as briquets cooled; were easily handled from machine, but produced high percentage of slack in handling afterwards. Fracture was rough and color brighter than in briquets from unwashed fuel. For analyses of briquets see page 145.

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ... per cent	39.0
Temperature of briquets ... °F	131	Passed ... do	61.0
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held ... do	71.0
Laboratory No. (see p. 40)	4318 / 4543	Passed (fines) ... do	29.0
Amount ... per cent	7	Fines through 10-mesh sieve ... do	93.8
Weight of—		Weathering test:	
Fuel briquetted ... pounds	30,000	Time exposed ... days	48
Briquets, average ... do	0.427	Condition	B.
Heat value per pound—		Water absorption:	
Fuel as received ... B. t. u.	12,994	In 19 days ... per cent	28.5
Fuel as fired ... do	12,391	Average for first 4 days ... do	4.0
Binder ... do	16,811	Specific gravity (apparent)	0.903

Extraction analyses.

	Pitches.		Fuel.	Briquets, test 169*.
Laboratory No.	4318	4543	3979	4627
Air-drying loss ... per cent			13.10	7.90
Extracted by CS_2:				
Air-dried ... do			.73	9.12
As received ... do	90.42	99.66	.63	8.40
Pitch in briquets, as received ... do				8.39

INDIAN TERRITORY.

INDIAN TERRITORY NO. 2.[a]

Bituminous coal from the Hartshorne bed, at Hartshorne, on the Rock Island Railroad, was designated "Indian Territory No. 2." The coal, as worked from the outcrop and by shafts at this place, averages 4 feet 1 inch in thickness.

Two samples of coal were shipped, as follows: Indian Territory No. 2 B, uninspected, consisted of slack screenings (through a $\frac{5}{8}$-inch shaking screen) and was used in steaming tests 418, 453 (on briquets), and 456 (on briquets); washing test 176; and briquetting tests 135, 136, 137, 138, 139, 145, 146, 147, 148*†, 149*, 157†, and 168. Indian Territory No. 2 C, shipped under the supervision of John W. Groves, consisted of lump coal over a 1-inch shaking screen, and was used in steaming test 455 and briquetting tests 153, 154, 155, and 156. Indian Territory Nos. 2 B and 2 C were used (mixed) in steaming test 417.

[a] For other tests of coal from this mine, made during 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 39, 67, 81, 124, 165; and Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 69, 215, 505, 1337, 1439, 1467.

CHEMICAL ANALYSES.

Indian Territory No. 2.

	Steaming tests.[a]					Briquetting tests.[b]				
	B.			417 (B and C).	455 (C).	B.				
	418.	453.	456.			135, 136.	137, 168.	145, 146, 147.	139.	149*.
Proximate:										
Moisture	2.92	3.29	2.85	2.88	2.70	3.61	3.85	2.87	2.80	2.13
Volatile matter	36.14	35.25	34.91	35.40	35.84	33.03	34.06	35.02	35.67	36.97
Fixed carbon	52.42	53.15	54.03	51.87	53.40	49.64	49.36	50.60	53.77	54.14
Ash	8.52	8.31	8.21	9.85	8.06	13.72	12.73	11.51	7.76	6.76
Sulphur	1.98	1.52	1.50	1.80	1.46	1.76	1.71	1.72	1.58	1.47
Ultimate:										
Hydrogen	4.94	4.93	4.87	4.89	4.95	4.65	4.54	4.48	4.91	5.04
Carbon	75.63	76.11	76.28	74.63	76.57	71.08	73.17	73.39	75.63	77.98
Nitrogen	1.91	1.69	1.71	1.88	1.79	1.46	1.61	1.49	1.52	1.78
Oxygen	6.70	7.11	7.15	6.61	6.91	6.75	5.66	7.02	8.33	6.79
Ash	8.78	8.59	8.45	10.14	8.28	14.23	13.24	11.85	7.98	6.91
Sulphur	2.04	1.57	1.54	1.85	1.50	1.83	1.78	1.77	1.63	1.50

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Indian Territory No. 2.

	B (slack).			B and C.	C (lump).
	Test 418.	Test 453.	Test 456 (w.)	Test 417.	Test 455.
Size as used:					
Over 1 inch ... per cent	25.5	See "Remarks" (below).	See "Remarks" (below).	25.2	(a)
½ inch to 1 inch ... do	31.4			27.6	
¼ inch to ½ inch ... do	18.6			18.7	
Under ¼ inch ... do	24.5			28.5	
Average diameter ... inch	0.78			0.75	
Duration of test ... hours	10.05	10.05	10.08	10.15	9.92
Heating value of fuel ... B. t. u. per pound of dry fuel	13,721	13,687	13,856	13,534	13,957
Force of draft:					
Under stack damper ... inch water	0.63	0.78	0.87	0.58	0.64
Above fire ... do	.11	.17	.14	.09	.17
Furnace temperature ... °F	.....	2,653	2,704	.....	2,807
Dry fuel used per square foot of grate surface per hour ... pounds	18.10	19.93	21.38	17.81	19.90
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.39	3.75	3.80	3.23	3.34
Percentage of rated horsepower of boiler developed	95.0	105.1	106.6	90.5	93.5
Water apparently evaporated per pound of fuel as fired ... pounds	7.81	7.60	7.23	7.57	6.82
Water evaporated from and at 212° F.:					
Per pound of fuel as fired ... do	9.10	9.12	8.65	8.83	8.17
Per pound of dry fuel ... do	9.38	9.42	8.90	9.09	8.39
Per pound of combustible ... do	10.65	10.80	10.00	10.62	9.52
Efficiency of boiler, including grate ... per cent	66.02	66.46	62.03	64.86	58.05
Fuel as fired:					
Per indicated horsepower hour ... pounds	3.11	3.10	3.27	3.20	3.46
Per electrical horsepower hour ... do	3.84	3.83	4.04	3.95	4.27
Dry fuel:					
Per indicated horsepower hour ... do	3.01	3.00	3.18	3.11	3.37
Per electrical horsepower hour ... do	3.72	3.71	3.92	3.84	4.16

[a] See page 148.

Remarks.—Test 453 on briquets from test 148*†: Briquets were badly broken up from weathering and handling. Fuel burned quickly, with medium flame, intense heat, and 4.5 per cent black smoke. Considerable of the slack from the briquets fell through the grates. Clinker was thin, dark gray in color, not porous, and stuck to the grate.

Test 456 on briquets from tests 138 and 157†: Briquets from test 138 burned readily, with short, yellow flame, intense heat, and 7 per cent black smoke. Briquets from test 157† burned well until clinker formed over the grate. Best results were obtained when briquets were fired whole; 8.5 per cent black smoke. Clinker on both tests was

very heavy and of a dark-purple color, and formed in layers. Water thrown into ash pit did not prevent clinker from sticking to grate.

Test 455 on briquets from tests 153, 154, 155, and 156 (equal parts): Square briquets did not give as good results as round ones, owing to holes in the fire, although they made less clinker on account of cooler fire; 8 per cent black smoke. Clinker was tough, purple in color; formed a thin layer over and stuck to the grate.

WASHING TEST

Indian Territory No. 2 B.

Test 176.—Size as shipped, slack. Size as used, slack. Jig used, modified Stewart. Raw coal, 38,000 pounds. Washed coal, 29,060 pounds; 78 per cent. Refuse, 8,940 pounds; 22 per cent.

Analyses.

	Raw coal.	Washed coal.
Moisture	6.27	6.61
Volatile matter	32.37	.....
Fixed carbon	47.07	.....
Ash	14.29	8.27
Sulphur	1.79	1.55

BRIQUETTING TESTS.

Indian Territory No. 2.

Tests 135, 136, 137, 145, 146, 147, 148†, and 168 (coal B, raw slack).*—There was no apparent difference in English briquets with 6, 7, and 8 per cent binder. A small lot with 5 per cent binder showed shortage of pitch. Pressure on machine was changed during making of Renfrow briquets, as indicated in tests. All briquets were satisfactory, having sharp edges, hard surfaces, and clean, rough fracture; could be handled from machine while warm and piled 5 feet high without sticking together or crushing. For analyses of briquets see page 147 (briquets from test 148*† under "Steaming test 453").

	Test 135.	Test 136.	Test 137.	Test 145.	Test 146.	Test 147.	Test 148*†.	Test 168.
Details of manufacture:								
Machine used	Eng.	Eng.	Eng.	Eng.	Eng.	Eng.	Renf.	Renf.
Temperature of briquets ...°F.	185	185	185	185	185	185	149	149
Binder—								
Kind	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.
Laboratory No. (see p. 40)	3258	3258	3296	3486	3623	3624	3486	3296
Amount ....per cent	6	7	8	6	7	8	8	8
Weight of—								
Fuel briquetted ....pounds	11,000	22,000	70,000	16,000	16,000	16,000	19,400	99,000
Briquets, average ....do	3.46	3.88	3.77	3.53	3.64	3.43	0.515	0.508
Heat value per pound—								
Fuel as received ....B. t. u.	12,400	12,400	12,400	12,033	12,033	12,033	12,033	12,400
Fuel as fired ....do	12,317	12,317	12,481	12,811	12,811	12,811	13,412	12,481
Binder ....do	16,373	16,373	16,427	16,241	16,241	16,241	16,407	16,427
Drop test (1-inch screen):								
Held ....per cent	.....	.....	.....	81.7	82.8	84.2	58.5	.....
Passed ....do	.....	.....	.....	18.3	17.2	15.8	41.5	.....
Tumbler test (1-inch screen):								
Held ....do	.....	74.8	.....	73.3	79.8	80.8	81.0	.....
Passed ....do	.....	25.2	.....	26.7	20.2	19.2	19.0	.....
Fines through 10-mesh sieve, per cent	.....	75.0	.....	86.5	85.6	75.5	95.4	.....
Weathering test:								
Time exposed ....days	239	239	239	145	145	145	144	239
Condition	B.	C.	B.	B.	A.	A.	B.	B.
Water absorption:								
In 16 days ....per cent	.....	.....	.....	8.6	10.2	11.4	12.9	.....
Average for first—								
13 days ....do	.....	.8	.....	1.62	.72	.84	.....	.....
6 days ....do	.....	.....	.....	.....	.....	.....	1.7	.....
Specific gravity (apparent)	.....	.....	.....	1.151	1.133	1.076	1.117	.....

Extraction analyses.[a]

	Fuel.		Briquets.				
			Tests 135, 136.	Test 137.	Tests 145, 146, 147.	Test 148*†.	Test 168.
Laboratory No.	3381	3472	3262	3342	3520	4086	3343
Air-drying loss.....per cent	1.50	3.80	1.50	.....	1.00	1.30	.....
Extracted by CS_2:							
Air-dried.....do	.33	.43	4.80	.....	8.87	6.11	.....
As received.....do	.32	.41	4.72	6.32	8.78	6.00	8.84
Pitch in briquets as received, per cent	.....	.....	5.50	7.32	10.19	6.57	10.40

[a] The extraction analyses of the pitches used can be found by referring to page 40.

Tests 138, 139, 149, and 157† (coal B, washed slack); tests 153, 154, 155, and 156 (coal C, lump).*—Tests 138 and 139 were made from the first sample sent to the plant, and tests 149* and 157† from the second sample. Excellent briquets were made with 8 per cent binder. The English briquets showed the advantage of higher pressure by being harder and closer grained and having smoother surfaces and sharper edges. Similar differences mark the superiority of these briquets over those from the same slack unwashed.

The briquets made from lump coal (C) may be considered as standing in value between those made from washed and those made from unwashed slack from the same mine; they are identical in appearance.

For analyses of briquets see page 147 (briquets from tests 138 and 157† under "Steaming test 456," from tests 153, 154, 155, and 156 under "Steaming test 455").

	B.				C.			
	Test 138.	Test 139.	Test 149*.	Test 157†.	Test 153.	Test 154.	Test 155.	Test 156.
Details of manufacture:								
Machine used	Eng.	Renf.	Renf.	Eng.	Eng.	Eng.	Eng.	Renf.
Temperature of briquets...° F.	185	149	149	185	185	185	185	14
Binder—								
Kind	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.	w.g.p.
Laboratory No. (see p. 40)	3624	3296	3624	3624	3486	3486	3486	3486
Amount.....per cent	8	8	8	8	6	7	8	8
Weight of—								
Fuel briquetted....pounds	16,000	20,000	40,000	8,000	1,000	1,000	1,000	8,000
Briquets, average.....do	3.31	0.451	0.476	3.34	3.11	3.19	3.14	0.490
Heat value per pound—								
Fuel as received....B. t. u.	.....	.....	.....	.....	13,630	13,630	13,630	13,630
Fuel as fired.....do	13,562	13,541	13,707	13,707	13,581	13,581	13,581	13,581
Binder.....do	16,427	16,427	16,193	16,193	16,407	16,407	16,407	16,407
Drop test (1-inch screen):								
Held.....per cent	88.9	60.0	56.0	85.5	79.8	84.6	86.4	70.0
Passed.....do	11.1	40.0	44.0	14.5	20.2	15.4	13.6	30.0
Tumbler test (1-inch screen):								
Held.....do	85.0	79.0	76.0	82.5	71.0	76.6	83.5	81.5
Passed (fines).....do	15.0	21.0	24.0	17.5	29.0	23.4	16.5	18.5
Fines through 10-mesh sieve, per cent	79.5	90.5	93.7	78.1	82.3	80.6	78.4	90.9
Weathering test:								
Time exposed.....days	128	127	149	128	239	239	239	182
Condition	B.	C.	B.	A.	C.	C.	C.	B.
Water absorption:								
In 19 days.....per cent	9.6	14.7	16.0	10.3	12.6	11.1	.....	13.5
In 15 days.....do	.....	.....	.....	.....	.....	.....	10.2	.....
Average for first—								
5 days.....do	1.20	2.0	2.26	1.06	.....	1.34	1.57	1.84
12 days.....do	.....	.....	.....	.....	0.93	.....	.....	.....
Specific gravity (apparent)	1.097	1.061	1.024	1.096	1.070	1.084	1.088	1.077

Extraction analyses.[a]

	B.					C.	
	Fuel.		Briquets.			Fuel.	Briquets, tests 153, 154, 155, 156.
			Test 139.	Test 149*.	Tests 138, 157†.		
Laboratory No.	3281	3487	3896	3559	4108	3657	4099
Air-drying loss.....per cent	.....	4.60	1.20	0.5	0.90	.....	0.80
Extracted by CS_2:							
Air-dried.....do	0.43	1.06	7.67	6.43	6.10	.....	5.75
As received.....do	.41	1.01	7.58	6.40	6.04	1.00	5.70
Pitch in briquets, as received, per cent	.....	.....	8.75	6.22	6.32	.....	5.56

[a] The extraction analysis of the pitches used can be found by referring to p. 40.

INDIAN TERRITORY NO. 8.

Bituminous coal sent in uninspected, designated Indian Territory No. 8, was used in steaming test 437 and washing test 175.

CHEMICAL ANALYSES.

Indian Territory No. 8.

	Steaming test 437.[a]		Steaming test 437.[a]
Proximate:		Ultimate:	
Moisture	2.80	Hydrogen	4.91
Volatile matter	35.67	Carbon	75.63
Fixed carbon	53.77	Nitrogen	1.52
Ash	7.76	Oxygen	8.33
Sulphur	1.58	Ash	7.98
		Sulphur	1.63

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Indian Territory No. 8 (washed. Renfrow briquets).

	Test 437.
Duration of test.....hours	7.45
Heating value of coal.....B. t. u. per pound dry coal	13,932
Force of draft:	
Under stack damper.....inch water	0.70
Above fire.....do	.05
Dry coal used per square foot of grate surface per hour.....pounds	19.31
Equivalent water evaporated per square foot of water-heating surface per hour.....do	3.43
Percentage of rated horsepower of boiler developed	96.0
Water apparently evaporated per ponud of coal as fired.....pounds	7.45
Water evaporated from and at 212° F.:	
Per pound of coal as fired.....do	8.64
Per pound of dry coal.....do	8.89
Per pound of combustible.....do	10.08
Efficiency of boiler, including grate.....per cent	61.62
Coal as fired:	
Per indicated horsepower hour.....pounds	3.27
Per electrical horsepower hour.....do	4.04
Dry coal:	
Per indicated horsepower hour.....do	3.18
Per electrical horsepower hour.....do	3.93

WASHING TEST.

Indian Territory No. 8.

Test 175.—Jig used, Stewart. Raw coal, 37,600 pounds. Washed coal, 32,300 pounds; 86 per cent. Refuse, 5,300 pounds; 14 per cent.

Analyses.

	Raw coal.	Washed coal.
Moisture	3.77	8.97
Volatile matter	32.65	.....
Fixed carbon	51.15	.....
Ash	13.43	8.46
Sulphur	1.79	1.56

INDIAN TERRITORY NO. 9.

Semianthracite coal from Panama, on the Kansas City Southern Railroad, was designated Indian Territory No. 9.

One sample, shipped uninspected, consisted of run-of-mine coal, and was used in steaming tests 449 and 450 (on briquets), and briquetting test 167.

CHEMICAL ANALYSES.

Indian Territory No. 9.

	Car sample.	Steaming tests.[a]	
		449.	450.
Laboratory No	4020	.....	4325
Air-drying loss	4.50	.....	.....
Proximate:			
Moisture	5.11	3.81	3.39
Volatile matter	13.65	13.62	17.15
Fixed carbon	73.21	76.16	72.04
Ash	8.03	6.41	7.42
Sulphur	1.18	1.17	1.15
Ultimate:			
Hydrogen	4.65	4.39	4.23
Carbon	78.37	84.26	82.89
Nitrogen	1.60	1.72	1.61
Oxygen	6.17	1.75	2.40
Ash	.....	6.66	7.68
Sulphur	.....	1.22	1.19
Calorific value determined (as received) calories	7,590	.....	.....
Calorific value determined (as received) B. t. u.	13,662	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Indian Territory No. 9 (run of mine).

		Test 449.	Test 450.
Size as used:			
Over 1 inch	per cent	7.5	See p. 152
½ inch to 1 inch	do	8.1	
¼ inch to ½ inch	do	12.4	
Under ¼ inch	do	72.0	
Average diameter	inch	0.35	
Duration of test	hours	10.2	9.97
Heating value of fuel	B. t. u. per pound dry fuel	14,682	14,602
Force of draft:			
Under stack damper	inch water	0.77	0.77
Above fire	do	.14	.12

STEAMING TESTS—Continued.

Indian Territory No. 9 (run of mine).

	Test 449.	Test 450.
Furnace temperature ..... °F.	2,513	2,738
Dry fuel used per square foot of grate surface per hour ..... pounds.	18.62	18.47
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.46	3.65
Percentage of rated horsepower of boiler developed	97.0	102.2
Water apparently evaporated per pound of fuel as fired ..... pounds.	7.51	8.00
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ..... do.	8.96	9.56
Per pound of dry fuel ..... do.	9.31	9.89
Per pound of combustible ..... do.	10.62	11.10
Efficiency of boiler, including grate ..... per cent.	61.24	65.41
Fuel as fired:		
Per indicated horsepower hour ..... pounds.	3.16	2.96
Per electrical horsepower hour ..... do.	3.90	3.65
Dry fuel:		
Per indicated horsepower hour ..... do.	3.04	2.86
Per electrical horsepower hour ..... do.	3.75	3.53

Remarks.—Test 450 on briquets from test 167: Fuel burned with short flame, developing very high temperature and no smoke. A small amount of clinker was formed, which did not stick to grates.

BRIQUETTING TEST.

Indian Territory No. 9 (run of mine).

Test 167.—Size as used: Over $\frac{1}{4}$ inch, 0.8 per cent; $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, 3.6 per cent; $\frac{1}{32}$ inch to $\frac{1}{16}$ inch, 12.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{32}$ inch, 25.2 per cent; through $\frac{1}{40}$ inch, 57.8 per cent. Excellent briquets made with 7 per cent pitch, which could be reduced by increasing pressure of machine. Briquets were hard, with smooth surface and glossy, clean fracture; easily handled from machine while hot, but became somewhat brittle when cold. For analyses of briquets see page 151 (steaming test 450).

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ..... per cent.	62.5
Temperature of briquets ..... °F.	176	Passed ..... do.	37.5
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. p.	Held ..... do.	82.5
Laboratory No. (see p. 40)	4120	Passed (fines) ..... do.	17.5
Amount ..... per cent.	7	Fines through 10-mesh sieve . do.	93.0
Weight of—		Weathering test:	
Fuel briquetted ..... pounds.	70,000	Time exposed ..... days.	31
Briquets, average ..... do.	0.459	Condition	B.
Heat value per pound—		Water absorption:	
Fuel as received ..... B. t. u.	13,662	In 18 days ..... per cent.	16.6
Fuel as fired ..... do.	14,103	Average for first 5 days ..... do.	2.62
Binder ..... do.	17,060	Specific gravity (apparent)	1.090

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 167.
Laboratory No.	4120	4020	4325
Air-drying loss ..... per cent.	.....	4.50	0.90
Extracted by CS_2:			
Air-dried ..... do.	.....	.50	6.20
As received ..... do.	97.70	.48	6.14
Pitch in briquets as received ..... do.	.....	.....	5.83

KANSAS.

KANSAS NO. 2.[a]

Bituminous coal from the lower Weir-Pittsburg bed at Yale, Crawford County, was designated Kansas No. 2 B. The coal, as worked at a depth of 36 feet at this place, averages 3 feet in thickness.

One sample consisted of slack coal, shipped uninspected, and was used in steaming tests (on briquets) 487, 488, and 495; washing tests 191 and 191a; and briquetting tests 182*†, 183*, 194*, 195, 199*, 203*, and 204*.

CHEMICAL ANALYSES.

Kansas No. 2 B.

	Car sample 4361.	Steaming tests.[a]			Briquetting tests.[b]			
		487.	488.	495.	195.	199.*	203.*	204.*
Proximate:								
Moisture	8.01	9.43	4.64	7.64	4.23	2.78	2.89	3.20
Volatile matter	26.39	29.71	28.40	32.49	32.64	31.67	33.04	33.95
Fixed carbon	45.22	43.67	46.56	51.52	53.57	46.78	52.26	51.53
Ash	20.38	17.19	20.40	8.35	9.56	18.77	11.81	11.32
Sulphur	4.70	4.15	4.49	3.60	3.36	4.36	3.84	3.82
Ultimate:								
Hydrogen		4.28	5.03	4.61	4.81	4.35	4.32	4.55
Carbon		66.12	64.05	74.58	76.20	66.00	72.13	73.25
Nitrogen		1.03	1.20	1.25	1.20	.96	1.09	1.12
Oxygen		5.01	3.62	6.62	4.34	4.89	6.33	5.40
Ash		18.98	21.39	9.04	9.99	19.32	12.18	11.73
Sulphur		4.58	4.71	3.90	3.51	4.78	3.95	3.95

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Kansas No. 2 B (briquets).

	Test 487.	Test 488.	Test 495 (w).
Duration of test ... hours	9.65	7.70	9.72
Heating value of fuel ... B. t. u. per pound dry fuel	12,193	11,767	13,811
Force of draft with reference to atmospheric pressure:			
Under stack damper ... inch water	0.82	0.80	0.84
Above fire ... do	.17	.17	.18
Furnace temperature ... °F			2,862
Dry fuel used per square foot of grate surface per hour ... pounds	19.43	22.00	20.30
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.10	3.44	3.81
Percentage of rated horsepower of boiler developed	86.8	96.6	106.8
Water apparently evaporated per pound of fuel as fired ... pounds	5.97	6.19	7.18
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	7.22	7.48	8.67
Per pound of dry fuel ... do	7.97	7.84	9.39
Per pound of combustible ... do	10.11	10.20	10.53
Efficiency of boiler, including grate ... per cent	63.12	64.34	65.66
Fuel as fired:			
Per indicated horsepower hour ... pounds	3.92	3.78	3.26
Per electrical horsepower hour ... do	4.84	4.67	4.03
Dry fuel:			
Per indicated horsepower hour ... do	3.55	3.61	3.01
Per electrical horsepower hour ... do	4.38	4.45	3.72

[a] For other tests of coal from this mine, made during 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 44, 81, 125, 159, and Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 84, 227, 593, 1345, 1443.

Remarks.—Test 487 on briquets from test 182*†; test 488 on briquets from test 183*. English briquets fired whole burned freely with hot fire and 2.5 per cent black smoke. Renfrow briquets burned quickly with medium flame, intense heat, and no smoke. English briquets made 40 per cent and Renfrow briquets 51 per cent clinker. Clinker in both tests was very thick, nonporous, hard to break up, and nearly black in color. It did not stick to grates.

Test 495 on briquets from test 194*. Burned freely with short flame, and high furnace temperature; without breaking; made 1.5 per cent black smoke; 46 per cent clinker; ash contained unburnt, fine coal, due to disintegration of briquets during combustion. (See p. 155.)

WASHING TESTS.

Kansas No. 2 B (slack).

	Test 191.	Test 191a.			Test 191.	Test 191a.
Duration of test.....hours..	2	3¾	Raw coal.....tons..		23.00	39.00
Jig adjustment:			Washed coal.....	...do.....	18.1	25.25
Make or number.....	Special.	Special.		per cent..	79	65
Speed.....r. p. m..	70	70	Refuse.....	tons.....	4.9	13.75
Stroke.....inches..	2½	2½		per cent..	21	35

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample.....	4361	8.01	20.38	.....	4.70	.....
Washed coal:						
Test 191.....	4410	12.11	8.88	56	3.72	21
Test 191a.....	4518	9.53	10.87	47	3.80	19
Refuse.....	.....	.....	76.50	.....	11.32	.....

Float and sink tests.

No. of test.	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analyses.			
					Ash.		Sulphur.	
		To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):								
1.....	1.36	.....	66	34	4.48	78	2.63	44
2.....	1.41	.....	74	26	5.31	74	2.78	41
3.....	1.47	.....	78	22	5.73	72	3.19	32
4.....	1.56	.....	81	19	6.18	70	3.31	30
On refuse (float)[a] of test 191:								
1.....	1.35	9	1.94	.....	4.30	.....	2.58	.....
2.....	1.40	10	2.16	.....	5.04	.....	2.92	.....
3.....	1.46	10	2.16	.....	7.53	.....	3.57	.....
4.....	1.53	10	2.16	.....	7.71	.....	3.81	.....

[a] Loss of good coal, 2.16 per cent.

BRIQUETTING TESTS.

Kansas No. 2 B.

Tests 182, 183*, 199* (raw slack).*—Size as used: Over ¼ inch, 1.0 per cent; $\frac{1}{10}$ inch to ¼ inch, 4.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 12.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 23.6 per cent; through $\frac{1}{40}$ inch, 58.0 per cent. Briquets showed the same characteristics as those made from washed coal, except that they were harder when cold; fracture harder and rougher, owing to high ash present. For analyses of briquets see page 153 (briquets from test 182*† under "Steaming test 487," from test 183* under "Steaming test 488").

Tests 194, 195, 203*, 204* (washed slack).*—Size as used: Over ¼ inch, 0.8 per cent; $\frac{1}{10}$ inch to ¼ inch, 4.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 12.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 21.4 per cent; through $\frac{1}{40}$ inch, 60.4 per cent. Satisfactory English briquets were made with 7 per cent binder and Renfrow briquets with 8 and 9 per cent binder; there being no apparent difference in these two kinds. All had smooth outer surface, were well molded, with sharp edges, clean, rough fracture, and did not break in handling while warm. After the briquets became cold those with 9 per cent binder showed less effect of abrasion than those with 8 per cent binder. Renfrow briquets showed deficiency of pressure. For analyses of briquets see page 153 (those from test 194* under "Steaming test 495").

	From raw slack.			From washed slack.			
	Test 182*†.	Test 183*.	Test 199*.	Test 194*.	Test 195.	Test 203*.	Test 204*.
Details of manufacture:							
Machine used	Eng.	Renf.	Renf.	Eng.	Eng.	Renf.	Renf.
Temperature of briquets ° F.	158	149	149	176	176	149	149
Binder—							
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4543	4543	4683	4543	4683	4683	4683
Amount per cent	7	7	8	7	7	8	9
Weight of—							
Fuel briquetted pounds	40,000	40,000	68,000	12,000	24,000	16,000	24,000
Briquets, average do	3.95	0.482	0.455	3.65	3.61	0.441	0.417
Heat value per pound—							
Fuel as received B. t. u.	10,640	10,640	10,640	13,243	13,243	13,243	13,243
Fuel as fired do	11,043	11,221	11,795	12,841	12,982	13,012	13,104
Binder do	16,969	16,969	16,637	16,969	16,637	16,637	16,637
Drop test (1-inch screen):							
Held per cent	89.1	69.0	61.0	84.9	81.4	64.0	52.5
Passed do	10.9	31.0	39.0	15.1	18.6	36.0	47.5
Tumbler test (1-inch screen):							
Held do	85.2	91.0	88.5	80.8	83.5	84.5	80.5
Passed (fines) do	14.8	9.0	11.5	19.2	16.5	15.5	19.5
Fines through 10-mesh sieve do	71.6	94.7	97.5	87.2	74.6	94.7	94.3
Weathering test:							
Time exposed days	12	12	.....	4	3	.....	.....
Condition	B.	A.	.....	A.	A.	.....	.....
Water absorption:							
In 19 days per cent	9.2	12.6	.....	.....	.....	.....	.....
In 13 days do	.....	.....	12.4	8.7	9.7	13.6	12.9
Average for first 4 days do	1.15	1.95	2.23	1.35	1.43	2.50	2.23
Specific gravity (apparent)	1.198	1.170	1.143	1.122	1.105	1.044	1.098

Extraction analyses.

	Pitches.		Fuel.		Briquets.						
					Test 182*†.	Test 183*.	Test 199*.	Test 194*.	Test 195.	Test 203*.	Test 204*.
Laboratory No.	4543	4683	4361	4518	4374	4380	.....	4422	4660	4654	4655
Air-drying loss per cent	.....	.....	6.60	8.20	7.00	3.00	.....	6.20	.....	.....	.....
Extracted by CS_2:											
Air-dried do	.....	.....	.50	.59	7.12	6.99	.....	7.14	.....	.....	.....
As received do	99.66	89.31	.47	.54	6.62	6.78	6.61	6.70	6.60	7.02	7.83
Pitch in briquets as received, per cent	.....	.....	.....	.....	6.21	6.36	6.91	6.30	6.83	7.30	8.21

KANSAS NO. 6.

Bituminous coal from Jewett, Linn County, on the Missouri Pacific Railroad, was designated Kansas No. 6. The coal, as worked at a depth of 88 feet at this place, averages 2 feet 10 inches in thickness.

This sample, shipped under the supervision of W. J. Von Borries, consisted of lump coal over a 1¼-inch bar screen and was used in making steaming tests 311 and 323; producer-gas test 101; washing test 148; coking tests 113 (raw) and 115 (washed); and cupola test 122 (washed coal).

Two mine samples were taken for chemical analysis. Sample 2790 was cut 2,000 feet northeast of the shaft, where the coal measured 2 feet 10 inches in thickness. Sample 2791 was cut 1,200 feet northwest of the bottom of the shaft, where the coal measured 2 feet 3 inches in thickness.

CHEMICAL ANALYSES.

Kansas No. 6.

	Mine samples.		Car sample.	Steaming tests.[a]	
				311.	323.
Laboratory No.	2790	2791	2843		
Air-drying loss	9.20	7.60	7.10		
Proximate:					
Moisture	11.13	10.12	9.04	8.28	11.71
Volatile matter	28.83	30.25	29.69	30.33	30.23
Fixed carbon	47.44	46.82	45.55	45.86	47.61
Ash	12.60	12.81	15.72	15.53	10.45
Sulphur	2.41	2.66	3.72	3.42	2.64
Ultimate:					
Hydrogen			5.01	4.45	4.78
Carbon			60.99	67.64	72.62
Nitrogen			1.06	1.18	1.26
Oxygen			13.50	6.07	6.52
Ash				16.93	11.83
Sulphur				3.73	2.99
Calorific value (as received):					
Determined, calories	6,233		6,190		
Determined, B. t. u.	11,219		11,142		
Calculated from ultimate analysis, calories			6,156		
Calculated from ultimate analysis, B. t. u.			11,081		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Kansas No. 6 (lump).

	Test 311.	Test 323 (w.).
Size as used:		
Over 1 inch, per cent	42.8	38.7
½ inch to 1 inch, do	21.4	25.3
¼ inch to ½ inch, do	13.7	17.7
Under ¼ inch, do	22.1	18.3
Duration of test, hours	9.98	7.20
Heating value of coal, B. t. u. per pound dry coal	12,343	13,135
Force of draft:		
Under stack damper, inch water	0.58	0.52
Above fire, do	.13	.15
Furnace temperature, °F.	2,313	2,670
Dry coal used per square foot of grate surface per hour, pounds	18.62	22.34

STEAMING TESTS—Continued.

Kansas No. 6 (lump).

	Test 311.	Test 323 (w.)
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	2.93	3.80
Percentage of rated horsepower of boiler developed	82.2	106.6
Water apparently evaporated per pound of coal as fired ... pounds	6.03	6.24
Water evaporated from and at 212° F.:		
Per pound of coal as fired ... do	7.23	7.53
Per pound of dry coal ... do	7.88	8.52
Per pound of combustible ... do	9.89	9.92
Efficiency of boiler, including grate ... per cent	61.65	62.64
Coal as fired:		
Per indicated horsepower hour ... pounds	3.91	3.75
Per electrical horsepower hour ... do	4.83	4.64
Dry coal:		
Per indicated horsepower hour ... do	3.59	3.32
Per electrical horsepower hour ... do	4.43	4.10

PRODUCER-GAS TEST.

Kansas No. 6 (lump).

Test 101.—Size as used: Over 1 inch, 64 per cent; ½ inch to 1 inch, 17 per cent; ¼ inch to ½ inch, 9 per cent; under ¼ inch, 10 per cent. Duration of test, 13⅔ hours. Average electrical horsepower, 198.9. Average b. t. u. gas per cubic foot, 155.2. Total coal fired, 4,500 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.73	1.56	1.33
Developed at switchboard	1.66	1.49	1.27
Per brake horsepower:			
Commercially available	1.47	1.33	1.13
Developed at engine	1.41	1.27	1.08
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.84	1.66	1.41
Developed at switchboard	1.76	1.58	1.35
Per brake horsepower:			
Commercially available	1.56	1.41	1.20
Developed at engine	1.49	1.35	1.15

Analyses.

Coal.		*Gas by volume.*	
Moisture	9.85	Carbon dioxide (CO_2)	8.2
Volatile matter	30.19	Carbon monoxide (CO)	21.0
Fixed carbon	46.68	Hydrogen (H_2)	12.7
Ash	13.28	Methane (CH_4)	2.1
Sulphur	3.04	Nitrogen (N_2)	55.4
		Ethylene (C_2H_4)	.6

WASHING AND COKING TESTS.

Kansas No. 6 (lump).

Washing test 148.—Size as used, crushed to 2-inch. Jig used, Stewart. Raw coal, 24,000 pounds; washed, 22,000 pounds; refuse, 2,000 pounds.

Coking tests.

	Test 113 (raw).	Test 115 (w.).
Size as used	f. c.	f. c.
Duration of test ... hours	47	49
Coal charged ... pounds	10,000	12,000
Coke produced ... do	5,443	6,439
Coke produced ... per cent	54.43	53.66
Breeze produced ... pounds	341	299
Breeze produced ... per cent	3.41	2.49
Total yield ... do	57.84	56.15

Remarks.—Test 113: Light-gray color; strong, heavy coke; ash and sulphur high. Test 115: Light gray and silvery; strong, heavy coke; ash and sulphur reduced by washing (compare test 113), but still high.

Analyses.

	Washing test 148.		Coking test 113.		Coking test 115.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	9.04	12.63	8.58	1.01	12.29	0.59
Volatile matter	29.69	.....	30.27	.64	30.30	.56
Fixed carbon	45.55	.....	45.92	75.07	47.21	82.78
Ash	15.72	10.16	15.23	23.28	10.20	16.07
Sulphur	3.72	2.47	3.47	3.45	2.63	2.49

Cupola test of coke made from Kansas No. 6 coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
122	115	1.90	7	97.22	Coke	180	63	63	62	62	430
					Pig iron	540	428	428	427	427	2,250
					Scrap	180	143	143	142	142	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
122	8.57 a. m.	7	7	1,468	230	1,698	33	3,087	5.70	6.80	1,098	132

LADLE RECORD.

Ladle No.	Pounds.	Time (a. m.).	Ladle No.	Pounds.	Time (a. m.).
1	133	9.16	10	80	9.26
2	111	9.16½	11	99	9.27
3	102	9.19½	12	82	9.28
4	83	9.20	13	61	9.34
5	100	9.22	14	75	9.35
6	98	9.22½	15	71	9.36
7	89	9.23	16	47	9.36½
8	103	9.23½	17	54	9.37
9	80	9.24			

[a] Sulphur in ash, 0.02 per cent.

KENTUCKY.

KENTUCKY NO. 2.[a]

Coke breeze from Earlington, Hopkins County, on the Louisville and Nashville Railroad, was designated Kentucky No. 2 B. A sample shipped uninspected was used in washing test 143, in briquetting test 102, and mixed with Illinois No. 20 in briquetting tests 103 and 104 (p. 88).

WASHING TEST.

Kentucky No. 2 B (coke breeze).

Test 143.—Jig used, Stewart. Ash: Raw, 46.30 per cent; washed, 26.10 per cent reduction, 44 per cent.

BRIQUETTING TEST.

Kentucky No. 2 B (coke breeze).

Test 102.—Size as used: Over ¼ inch, 10.25 per cent; $\frac{1}{16}$ inch to ¼ inch, 31 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 18.75 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 18.55 per cent; through $\frac{1}{40}$ inch, 21.45 per cent. Machine used, English; temperature of briquets, 179.6° F. Binder: Kind, c. t. p. and w. g. p.; amount, 6 and 7 per cent. Weight of fuel briquetted, 50,000 pounds.

Briquets were soft when hot, but on cooling were hard enough to handle satisfactorily. Various mixtures made no apparent difference. All briquets showed coarse structure and were easily fractured. Attempted boiler tests were discontinued owing to difficulty in maintaining steam. Broken briquets burned better than whole ones. For pitch analyses see page 40 (Nos. 2729, 2735, and 2748). All these briquets were sent to the Big Four Railway for preliminary locomotive test. The results were unsatisfactory.

KENTUCKY NO. 8.

Bituminous coal from bed No. 1 B, or "Bell-coal" bed, at Sturges, Union County, on the Illinois Central Railroad, was designated Kentucky No. 8. The coal, as worked at a depth of 40 feet at this place, averages 2 feet 8 inches in thickness.

One sample, shipped under the supervision of F. B. Tough, consisted of run-of-mine coal, and was used in steaming tests 434 and 443; coking tests 164 and 165; and cupola tests 147, 155, and 156.

Two mine samples were taken for chemical analysis. Sample 3678 was taken 100 feet north of the opening, where the coal measured 2 feet 7¼ inches in thickness. Sample 3679 was taken 60 feet north of the opening, where the coal measured 2 feet 9¼ inches in thickness.

[a] For results of earlier tests of Kentucky No. 2 coal, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 46, 81, 159; and Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 91, 232, 649, 1348, 1444.

CHEMICAL ANALYSES.

Kentucky No. 8.

	Mine samples.		Car sample.	Steaming tests.[a]	
				434.	443.
Laboratory No.	3678	3679	3860		
Air-drying loss	5.10	5.70	3.20		
Proximate:					
Moisture	7.46	8.09	5.46	5.76	5.53
Volatile matter	30.69	30.10	30.99	30.36	29.68
Fixed carbon	57.25	56.65	55.63	56.21	57.05
Ash	4.60	5.16	7.92	7.67	7.74
Sulphur	.97	1.07	1.18	1.28	1.10
Ultimate:					
Hydrogen			5.07	4.72	4.73
Carbon			72.59	76.87	77.01
Nitrogen			1.19	1.26	1.26
Oxygen			12.05	7.65	7.65
Ash				8.14	8.19
Sulphur				1.36	1.16
Calorific value determined (as received) calories	7,494		7,355		
Calorific value determined (as received) B. t. u.	13,489		13,239		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Kentucky No. 8.

		Test 434.	Test 443.
Size as used:			
Over 1 inch	per cent	29.9	27.7
½ inch to 1 inch	do	23.4	20.6
¼ inch to ½ inch	do	15.6	15.4
Under ¼ inch	do	31.1	36.3
Average diameter	inch	0.77	0.80
Duration of test	hours	9.1	9.72
Heating value of coal	B. t. u. per pound dry coal	14,026	14,044
Force of draft:			
Under stack damper	inch water	0.66	0.79
Above fire	do	.05	.14
Furnace temperature	° F		2,778
Dry coal used per square foot of grate surface per hour	pounds	19.65	20.12
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	3.57	3.71
Percentage of rated horsepower of boiler developed		100.0	104.1
Water apparently evaporated per pound of coal as fired	pounds	7.35	7.44
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	8.56	8.73
Per pound of dry coal	do	9.08	9.24
Per pound of combustible	do	10.12	10.36
Efficiency of boiler, including grate	per cent	62.52	63.54
Coal as fired:			
Per indicated horsepower hour	pounds	3.30	3.24
Per electrical horsepower hour	do	4.08	4.00
Dry coal:			
Per indicated horsepower hour	do	3.11	3.06
Per electrical horsepower hour	do	3.84	3.78

COKING TESTS.

Kentucky No. 8.

		Test 164.	Test 165.
Size as shipped		r. o. m.	r. o. m.
Size as used		f. c.	f. c.
Duration of test	hours	49	51
Coal charged	pounds	12,450	12,840
Coke produced	do	7,200	7,845
	per cent	57.83	61.10
Breeze produced	pounds	371	361
	per cent	2.98	2.81
Total yield	do	60.81	63.91

Remarks.—Test 164: Gray color, with a little silvery deposit of carbon; breakage good, regular-sized pieces; cell structure large. Test 165: Gray color, with a little silvery deposit of carbon; breakage good, large pieces of regular size; cell structure large. Some improvement over test 164; yield somewhat higher, with increase in ash and sulphur.

Analyses.

	Test 164.		Test 165.	
	Coal.	Coke.	Coal.	Coke.
Moisture	4.97	0.50	5.49	0.47
Volatile matter	30.87	.65	30.36	.50
Fixed carbon	56.66	87.96	55.49	86.10
Ash	7.50	10.89	8.66	12.93
Sulphur	1.23	.93	1.27	1.14

Cupola tests of coke made from Kentucky No. 8 coal.

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
147	164	1.90	7	97.22	Coke	200	58	58	57	57	430
					Pig iron	800	550	550	550	550	3,000
155	164	1.90	6	93.05	Coke	210	73	73	72	72	500
					Pig iron	840	540	540	540	540	3,000
156	164	1.90	8	93.06	Coke	200	44	44	44	43	375
					Pig iron	800	550	550	550	550	3,000

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
147	3.30 p. m.	7	11	1,556	403	1,959	31	3,791	5.53	4.70	900	76
155	3.40 p. m.	7	8	2,101	361	2,462	38	3,887	5.85	5.93	360	79
156	10.56 a. m.	7	11	2,124	203	2,327	32	4,551	7.94	5.80	499	82

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (pounds).	Silicon.		Manganese.		Sulphur.		Content of coke combined with iron melted (per cent).
			Per cent.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	
147	Pig iron		2.12	41.53	0.178	3.487	0.59	1.1558	4.65
	Melted iron:								
	Amount		1.80	35.26	.096	1.881	.067	1.3125	
	Gain or loss		−15.12	− 6.27	−46.06	−1.606	+.008	+ .1567	
	Coke	362					.93	3.3666	
155	Pig iron		2.12	52.19	.178	4.382	.059	1.4526	12.37
	Melted iron:								
	Amount		1.72	42.35	.123	3.028	.079	1.9450	
	Gain or loss		−18.85	− 9.84	−30.90	−1.354	+.020	+ .4924	
	Coke	429					.93	3.9897	
156	Pig iron		2.12	49.33	.178	4.142	.059	1.3729	19.95
	Melted iron:								
	Amount		1.82	42.35	.111	2.583	.083	1.9314	
	Gain or loss		−14.15	− 6.98	−37.64	−1.559	+.024	+ .5585	
	Coke	301					.93	2.7993	

Cupola tests of coke made from Kentucky No. 8 coal—Continued.

LADLE RECORD.

Ladle No.	Test 147.		Test 155.		Test 156.		Ladle No.	Test 147.		Test 155.		Test 156.	
	Pounds.	Time (p.m.).	Pounds.	Time (p. m.).	Pounds.	Time (a. m.).		Pounds.	Time (p. m.).	Pounds.	Time (p. m.).	Pounds.	Time (a. m.).
1	86	3.47	67	3.54	32	11.10	14	86	4.08	106	4.12	107	11.28
2	86	3.47½	97	3.57	94	11.13	15	90	4.08½	85	4.14	94	11.29
3	40	3.48	39	3.57½	82	11.13½	16	84	4.09	81	4.14½	91	11.29½
4	72	3.52	81	4.00	70	11.18	17	82	4.11	105	4.15	93	11.30
5	91	3.52½	113	4.01	102	11.18½	18	44	4.12	76	4.17	89	11.32
6	94	3.53	85	4.03	100	11.19	19			76	4.17½	102	11.32½
7	67	3.56	87	4.03½	70	11.22	20			104	4.18	100	11.33
8	102	3.56½	103	4.04	101	11.22½	21			66	4.23	85	11.36
9	98	3.57	90	4.07	102	11.23	22			64	4.23½	100	11.36½
10	88	4.03	79	4.07½	59	11.24	23			85	4.24	103	11.37
11	84	4.03½	108	4.08	104	11.24½	24			65	4.25	75	11.39
12	94	4.04	84	4.11	92	11.27	25			55	4.25½		
13	168	4.04½	75	4.11½	77	11.27½	26			25	4.26		

Remarks.—Tests 147, 155, 156: Pig iron used from car 27633; temperature of iron, medium.

KENTUCKY NO. 9.

Bituminous coal from bed No. 9, at McHenry, Ohio County, on the Illinois Central Railroad, was designated Kentucky No. 9. The coal, as mined at a depth of 50 feet at this place, averages 4 feet 6 inches in thickness.

Two samples were shipped under the supervision of K. M. Way, as follows: Kentucky No. 9 A consisted of nut coal through a 1⅛-inch screen and over a ⅜-inch screen, and was used in washing test 182, coking test 167, and cupola tests 149, 162, and 163. Kentucky No. 9 B consisted of run-of-mine coal, and was used in steaming test 462.

Two mine samples were taken for chemical analysis. Sample 3722 was taken 200 feet north of the shaft, where the coal measured 4 feet 6 inches in thickness. Sample 3723 was taken 550 feet north of the shaft, where the coal measured 4 feet 5¾ inches in thickness.

CHEMICAL ANALYSES.

Kentucky No. 9.

	Mine samples.		Car sample (A).	Steaming test 462.[a]
Laboratory No.	3722	3723	3865	
Air-drying loss	3.30	2.90	3.50	
Proximate:				
Moisture	10.03	9.89	8.70	8.04
Volatile matter	36.06	35.70	35.00	32.63
Fixed carbon	46.24	45.72	47.34	49.28
Ash	7.67	8.69	8.96	10.05
Sulphur	2.56	2.45	3.14	2.97
Ultimate:				
Hydrogen			5.61	4.83
Carbon			65.63	71.12
Nitrogen			1.20	1.45
Oxygen			15.46	8.44
Ash				10.93
Sulphur				3.23
Calorific value determined (as received) calories	6,709	6,626	6,710	
Calorific value determined (as received) B. t. u.	12,076	11,927	12,078	

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Kentucky No. 9 B.

		Test 462.
Size as used:		
Over 1 inch	per cent	32.3
½ inch to 1 inch	do	26.4
¼ inch to ½ inch	do	16.6
Under ¼ inch	do	24.7
Average diameter	inch	0.83
Duration of test	hours	10
Heating value of coal	B. t. u. per pound dry coal	13,084
Force of draft:		
Under stack damper	inch water	0.70
Above fire	do	.19
Furnace temperature	°F	2,742
Dry coal used per square foot of grate surface per hour	pounds	21.48
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.69
Percentage of rated horsepower of boiler developed		103.5
Water apparently evaporated per pound of coal as fired	pounds	6.55
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	7.92
Per pound of dry coal	do	8.61
Per pound of combustible	do	9.97
Efficiency of boiler, including grate	per cent	63.55
Coal as fired:		
Per indicated horsepower hour	pounds	3.57
Per electrical horsepower hour	do	4.41
Dry coal:		
Per indicated horsepower hour	do	3.28
Per electrical horsepower hour	do	4.05

WASHING AND COKING TESTS.

Kentucky No. 9 A (nut).

Washing test 182.—Jig used, Stewart. Raw coal, 19,125 pounds; washed coal, 15,698 pounds, 82 per cent; refuse, 3,427 pounds, 18 per cent.

Coking test 167.—Size as used, washed, finely crushed. Duration of test, 51 hours. Coal charged, 12,190 pounds. Coke produced, 6,360 pounds, 52.17 per cent. Breeze produced, 309 pounds, 2.54 per cent. Total yield, 54.71 per cent. Light gray and silvery; fine-fingered coke; high in sulphur; good coke.

Analyses.

	Washing test 182.		Coking test 167.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	8.70	9.09	9.12	1.01
Volatile matter	35.00	.....	35.42	.69
Fixed carbon	47.34	.....	47.88	86.46
Ash	8.96	7.22	7.58	11.84
Sulphur	3.14	2.61	2.58	1.96

Cupola tests of coke made from Kentucky No. 9 A coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio, iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
149	167	1.86	7	95.83	Coke	170	65	65	65	65	430
					Pig iron	680	580	580	580	580	3,000
162	167	1.86	8	94.44	Coke	170	52	51	51	51	375
					Pig iron	680	580	580	580	580	3,000
163	167	1.86	6	98.61	Coke	190	78	78	77	77	500
					Pig iron	760	560	560	560	560	3,000

Cupola tests of coke made from Kentucky No. 9 A coal (washed)—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Ratio per hour.	Ratio, iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
149	3.08 p. m.	7	9	2,282	228	2,510	28	5,378	6.66	8.0	250	53
162	10.45 a. m.	7	10	2,161	356	2,517	32	4,719	7.70	5.47	319	48
163	3.35 p. m.	7	10	2,230	123	2,353	42	3,361	5.00	2.97	558	29

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (pounds).	Silicon.		Manganese.		Sulphur.		Content of coke combined with iron melted (per cent).
			Per cent.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	
149	Pig iron		2.12	53.21	0.178	4.468	0.059	1.4809	6.69
	Melted iron:								
	Amount		1.83	45.93	.133	3.338	.079	1.9829	
	Gain or loss		−13.68	− 7.28	−25.29	−1.130	+ .020	+ .5020	
	Coke	383					1.96	7.5068	
162	Pig iron		2.10	52.86	.163	4.103	.098	2.4667	7.73
	Melted iron:								
	Amount		1.76	44.30	.120	3.020	.118	2.9701	
	Gain or loss		−16.19	− 8.56	−26.39	−1.083	+ .020	+ .5034	
	Coke	332					1.96	6.5072	
163	Pig iron		2.10	49.41	.163	3.835	.098	2.4059	8.29
	Melted iron:								
	Amount		1.73	40.71	.096	2.259	.135	3.1765	
	Gain or loss		−17.61	− 8.70	−41.09	−1.576	+ .037	+ .7706	
	Coke	474					1.96	9.2924	

LADLE RECORD.

Ladle No.	Test 149.		Test 162.		Test 163.		Ladle No.	Test 149.		Test 162.		Test 163.	
	Lbs.	Time (p.m.).	Lbs.	Time (a.m.).	Lbs.	Time (p.m.).		Lbs.	Time (p.m.).	Lbs.	Time (a.m.).	Lbs.	Time (p.m.).
1	90	3.23	84	11.00	66	3.49	14	106	3.34	84	11.14½	136	4.12
2	50	3.23½	96	11.03	114	3.51	15	83	3.35	100	11.15	86	4.17
3	78	3.25	105	11.03½	110	3.54	16	96	3.35½	80	11.18	95	4.17½
4	96	3.25½	96	11.04	103	3.55	17	110	3.36	86	11.18½	130	4.18
5	69	3.26	80	11.07	30	3.55½	18	83	3.37	96	11.19	90	4.24
6	88	3.28	101	11.07½	128	4.02	19	104	3.37½	126	11.23	148	4.24½
7	102	3.28½	89	11.08	96	4.02½	20	102	3.39	69	11.23½	98	4.25
8	118	3.29	82	11.09	97	4.03	21	78	3.39½	79	11.24	88	4.26
9	91	3.31	97	11.09½	100	4.07	22	97	3.40	66	11.25	98	4.27
10	100	3.31½	82	11.11	91	4.07½	23	97	3.41	130	11.26		
11	115	3.32	83	11.11½	126	4.08	24	67	3.43	69	11.27		
12	79	3.33	93	11.12	100	4.11	25	85	3.45				
13	98	3.33½	88	11.14	100	4.11½							

Remarks.—Test 149: Pig iron used from car 27633. Iron hot. Tests 162 and 163: Pig iron used from car 131943. Temperature of iron, medium.

MARYLAND.

MARYLAND NO. 2.

Bituminous coal from the Big vein or Pittsburg bed at Frostburg, Allegany County, on the Baltimore and Ohio Railroad was designated Maryland No. 2. The coal, as worked from the outcrop at this place, averages 8 feet 10 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in steaming tests 490, 493 (on briquets), and 518 (on briquets), and briquetting tests 191, 192, 193, and 231†.

Two mine samples were taken for chemical analysis. Sample 4334 was taken 6,600 feet southwest of the opening, where the coal measured 9 feet 4 inches in thickness. Sample 4335 was taken 4,500 feet south of the opening, where the coal measured 8 feet 3¾ inches in thickness.

CHEMICAL ANALYSES.

Maryland No. 2.

	Mine samples.		Steaming tests.[a]				Steaming tests.[a]		
			490.	493.	518.		490.	493.	518.
Laboratory No.	4334	4335	.....	4415	4767	Ultimate:			
Air-drying loss	2.00	1.80	.....	.....	.....	Hydrogen	4.44	4.33	4.61
Proximate:						Carbon	82.18	81.52	83.26
Moisture	2.54	2.47	2.35	6.83	4.21	Nitrogen	1.48	1.79	1.64
Volatile matter	18.23	18.17	16.97	19.71	20.71	Oxygen	2.77	3.44	2.68
Fixed carbon	73.09	73.06	72.53	66.01	68.54	Ash	8.35	8.00	6.83
Ash	6.14	6.30	8.15	7.45	6.54	Sulphur	.78	.92	.98
Sulphur	.87	.79	.76	.86	.94				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Maryland No. 2.

	Test 490.	Test 493.	Test 518.
Size as used:			
Over 1 inch ... per cent	17.4	See p. 166.	See p. 166.
½ inch to 1 inch ... do	20.8		
¼ inch to ½ inch ... do	20.2		
Under ¼ inch ... do	41.6		
Average diameter ... inch	.60		
Duration of test ... hours	9.63	10.00	5.42
Heating value of fuel ... B. t. u. per pound dry fuel	14,515	14,576	14,717
Force of draft:			
Under stack damper ... inch water	0.83	0.85	0.29
Above fire ... do	.22	.21	.16
Dry fuel used per square foot of grate surface per hour ... pounds	20.12	21.13	22.81
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	4.06	4.32	2.44
Percentage of rated horsepower of boiler developed	113.9	121.2	68.4
Water apparently evaporated per pound of fuel as fired ... pounds	8.16	7.87	8.45
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	9.87	9.52	10.25
Per pound of dry fuel ... do	10.11	10.22	10.70
Per pound of combustible ... do	11.24	11.35	12.23
Efficiency of boiler, including grate ... per cent	67.26	67.71	70.21
Fuel as fired:			
Per indicated horsepower hour ... pounds	2.87	2.97	2.76
Per electrical horsepower hour ... do	3.54	3.67	3.41
Dry fuel:			
Per indicated horsepower hour ... do	2.80	2.77	2.64
Per electrical horsepower hour ... do	3.45	3.42	3.26

Remarks.—Test 493 on equal weights of briquets from tests 191, 192, and 193; test 518 on briquets from test 231†; grate area reduced to 20.3 square feet. Square briquets were fired whole, burned freely, with intense heat, and no smoke. Bed more uniform with round briquets and temperature higher; no smoke. Square briquets made 56 per cent clinker; round briquets made 47 per cent clinker.

BRIQUETTING TESTS.

Maryland No. 2 (run of mine).

Tests 191, 192, 193, 231†.—Size as used: Over $\frac{1}{4}$ inch, 2.2 per cent; $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, 9.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 26 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 28.2 per cent; through $\frac{1}{40}$ inch, 33.8 per cent. Various proportions of binder (5, 6, and 7 per cent) made equally good briquets on English machine. Briquet surfaces were smooth, firm, with characteristic glossy fracture, and sharp edges. Renfrow briquets were satisfactory, but owing to faulty operation in heater best results were not obtained. Excellent briquets can be made from this coal with 5 per cent of binder. For analyses of briquets see page 165 (briquets from test 191, 192, and 193 under "Steaming test 493," from test 231† under "Steaming test 518").

	Test 191.	Test 192.	Test 193.	Test 231†.
Details of manufacture:				
Machine used	Eng.	Eng.	Eng.	Renf.
Temperature of briquets ..... °F.	185	185	185	131
Binder—				
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4543	4543	4543	4806
Amount ..... per cent	5	6	7	8
Weight of—				
Fuel briquetted ..... pounds	4,000	4,000	4,000	17,000
Briquets, average ..... do	3.35	3.32	3.47	0.453
Heat value per pound—				
Fuel as received ..... B. t. u.	14,162	14,162	14,162	14,162
Fuel as fired ..... do	13,581	13,581	13,581	14,098
Binder ..... do	16,969	16,969	16,969	16,864
Drop test (1-inch screen):				
Held ..... per cent	75.9	79.3	82.5	24.0
Passed ..... do	21.1	20.7	17.5	76.0
Tumbler test (1-inch screen):				
Held ..... do	74.0	78.2	80.2	66.5
Passed (fines) ..... do	26.0	21.8	19.8	33.5
Fines through 10-mesh sieve ..... do	75.6	77.8	63.0	85.0
Weathering test:				
Time exposed ..... days	5	5	5	.....
Condition	A.	A.	A.	.....
Water absorption:				
In 19 days ..... per cent	11.9	15.6	10.5	14.4
Average for first 4 days ..... do	1.45	1.85	1.30	2.25
Specific gravity (apparent)	1.118	1.076	1.143	1.071

Extraction analyses.

	Pitches.		Fuel.	Briquets.	
				Tests 191, 192, 193.	Test 231†.
Laboratory No.	4543	4806	4335	4415	4767
Air-drying loss ..... per cent	.....	.....	1.80	6.00	3.40
Extracted by CS_2:					
Air-dried ..... do	.....	.....	.21	5.77	7.88
As received ..... do	99.66	96.90	.20	5.42	7.61
Pitch in briquets as received ..... do	.....	.....	.....	5.25	7.69

MISSOURI.

MISSOURI NO. 5.

Bituminous coal from Higbee, Randolph County, on the Chicago and Alton Railroad, was designated Missouri No. 5. The coal, as worked at a depth of 170 feet at this place, averages 3 feet 10 inches in thickness.

This sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in steaming tests 319 and 320, washing test 149, coking test 116 (washed coal), and cupola test 123.

Two mine samples were taken for chemical analysis. Sample 2795 was cut 3,400 feet northwest of the shaft, where the coal measured 3 feet 10 inches in thickness. Sample 2796 was cut 5,000 north of the shaft, where the coal measured 3 feet 10 inches in thickness.

CHEMICAL ANALYSES.

Missouri No. 5.

	Mine samples.		Car sample.	Steaming tests.[a]	
				319.	320.
Laboratory No	2795	2796	2865		
Air-drying loss	10.80	11.50	11.40		
Proximate:					
Moisture	13.38	13.89	12.92	13.37	12.24
Volatile matter	34.17	33.36	33.64	31.46	31.55
Fixed carbon	42.43	41.23	39.82	39.78	40.10
Ash	10.02	11.52	13.62	15.39	16.11
Sulphur	4.48	4.19	5.03	5.35	5.33
Ultimate:					
Hydrogen			5.43	4.43	4.40
Carbon			57.16	63.53	63.13
Nitrogen			.90	1.01	1.00
Oxygen			17.86	7.90	7.04
Ash				17.76	18.36
Sulphur				6.18	6.07
Calorific value (as received):					
Determined, calories	6,158		5,860		
Determined, B. t. u.	11,084		10,548		
Calculated from ultimate analysis, calories			5,834		
Calculated from ultimate analysis, B. t. u.			10,501		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Missouri No. 5 (run of mine).

	Test 319.	Test 320.
Size as used:		
Over 1 inch, per cent	23.5	20.1
½ inch to 1 inch, do	22.9	21.0
¼ inch to ½ inch, do	19.3	18.8
Under ¼ inch, do	34.3	40.1
Duration of test, hours	9.63	8.35
Heating value of coal, B. t. u. per pound dry coal	11,747	11,668
Force of draft:		
Under stack damper, inch water	0.61	0.73
Above fire, do	.22	.34
Furnace temperature, °F	2,368	
Dry coal used per square foot of grate surface per hour, pounds	18.64	22.24
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	2.79	3.38

STEAMING TESTS—Continued.

Missouri No. 5 (run of mine).

		Test 319.	Test 320.
Percentage of rated horsepower of boiler developed		87.1	94.7
Water apparently evaporated per pound of coal as fired	pounds	5.39	5.54
Water evaporated from and at 212° F:			
Per pound of coal as fired	do	6.49	6.67
Per pound of dry coal	do	7.49	7.60
Per pound of combustible	do	9.36	9.60
Efficiency of boiler, including grate	per cent	61.57	62.90
Coal as fired:			
Per indicated horsepower hour	pounds	4.36	4.24
Per electrical horsepower hour	do	5.38	5.24
Dry coal:			
Per indicated horsepower hour	do	3.77	3.72
Per electrical horsepower hour	do	4.66	4.59

WASHING AND COKING TESTS.

Missouri No. 5 (run of mine).

Washing test 149.—Size as used, crushed to 2-inch. Jig used, Stewart. Raw coal, 15,300 pounds; washed coal, 12,900 pounds; refuse, 2,400 pounds.

Coking test 116.—Size as used, washed, finely crushed. Duration of test, 33 hours. Coal charged, 10,000 pounds. Coke produced, 4,903 pounds; 49.03 per cent. Breeze produced, 299 pounds; 2.99 per cent. Total yield, 52.02 per cent. Light gray and silvery. Washing does not sufficiently reduce ash and sulphur; too high in sulphur for metallurgical purposes.

Analyses.

	Washing test 149.		Coking test 116.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	12.92	13.93	13.68	1.12
Volatile matter	33.64	.....	34.82	.73
Fixed carbon	39.82	.....	42.26	82.64
Ash	13.62	9.08	9.24	15.51
Sulphur	5.03	3.62	3.60	3.40

Cupola test of coke made from Missouri No. 5 coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
123	116	1.88	7	92.36	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
123	3.16 p. m.	7	5	1,964	423	2,387	34	4,212	6.25	9.06	341	48

Cupola test of coke made from Missouri No. 5 coal (washed)—Continued.

LADLE RECORD.

Ladle No.	Test 123.		Ladle No.	Test 123.	
	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).
1	67	3.29	16	58	3.46
2	85	3.33	17	70	3.46½
3	81	3.34	18	94	3.47
4	54	3.37	19	59	3.48
5	53	3.37½	20	45	3.48½
6	92	3.38	21	90	3.49
7	62	3.39	22	70	3.50
8	66	3.40	23	56	3.51
9	69	3.41	24	90	3.52
10	51	3.42	25	45	3.52½
11	63	3.43	26	69	3.53
12	60	3.43½	27	92	3.54
13	79	3.44	28	52	3.54½
14	91	3.45	29	39	3.55
15	62	3.45½			

Remarks.—Test 123: temperature of iron, medium.

MISSOURI NO. 6.

Bituminous coal from a mine 1 mile east of Huntsville, Randolph County, on the Wabash Railroad, was designated Missouri No. 6. The coal, as worked at a depth of 77 feet at this place, averages 3 feet 8 inches in thickness. This sample, shipped under the supervision of John W. Groves, consisted of lump coal over a 6-inch bar screen, and was used in making steaming tests 326 and 327. This sample was also allotted to be used in washing test 155, but the coal was burned in the fire at the plant.

Two mine samples were taken for chemical analysis. Sample 2817 was cut 900 feet north of the shaft, where the coal measured 4 feet in thickness. Sample 2818 was cut 4,000 feet southwest of the shaft, where the coal measured 3 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Missouri No. 6.

	Mine samples.		Car sample.	Steaming tests.[a]	
				326.	327.
Laboratory number	2817	2818	2904		
Air-drying loss	11.80	8.60	11.60		
Proximate:					
Moisture	14.01	11.38	13.80	13.73	12.93
Volatile matter	33.49	37.10	34.29	32.82	34.21
Fixed carbon	42.21	43.07	40.17	39.96	41.63
Ash	10.29	8.45	11.74	13.49	11.23
Sulphur	5.23	3.57	5.60	6.05	5.31
Ultimate:					
Hydrogen			5.48	4.44	4.65
Carbon			58.09	65.24	68.33
Nitrogen			.96	1.08	1.13
Oxygen			18.13	6.59	6.89
Ash				15.64	12.90
Sulphur				7.01	6.10
Calorific value (as received):					
Determined, calories	6,128		5,998		
Determined, B. t. u.	11,030		10,796		
Calculated from ultimate analysis, calories			5,926		
Calculated from ultimate analysis, B. t. u.			10,667		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Missouri No. 6 (lump).

		Test 326.	Test 327.
Size as used:			
Over 2 inches	per cent	.....	25.7
2 inches to 1½ inches	do	.....	27.4
Over 1 inch	do	36.5	.....
½ inch to 1½ inches	do	.....	19.2
½ inch to 1 inch	do	23.3	.....
¼ inch to ½ inch	do	16.6	12.0
Under ¼ inch	do	23.6	15.7
Duration of test	hours	9.92	10.03
Heating value of coal	B. t. u. per pound dry coal	12,155	12,677
Force of draft:			
Under stack damper	inch water	0.73	0.75
Above fire	do	.19	.18
Furnace temperature	°F.	2,476	2,561
Dry coal used per square foot of grate surface per hour	pounds	21.82	23.06
Equivalent water evaporated per square foot of water-heating surface per hour, pounds		3.47	3.66
Percentage of rated horsepower of boiler developed		97.4	102.7
Water apparently evaporated per pound of coal as fired	pounds	5.71	5.75
Water evaporated from and at 212 °F.:			
Per pound of coal as fired	do	6.88	6.93
Per pound of dry coal	do	7.98	7.96
Per pound of combustible	do	9.64	9.30
Efficiency of boiler, including grate	per cent	63.40	60.64
Coal as fired:			
Per indicated horsepower hour	pounds	4.11	4.08
Per electrical horsepower hour	do	5.08	5.04
Dry coal:			
Per indicated horsepower hour	do	3.54	3.55
Per electrical horsepower hour	do	4.38	4.39

MISSOURI NO. 7.

Bituminous coal from a mine one-half mile northwest of Novinger, Adair County, on the Quincy, Omaha and Kansas City Railroad, was designated Missouri No. 7. The coal, as worked at a depth of 88 feet at this place, averages 3 feet in thickness. This sample, shipped under the supervision of W. J. Von Borries, consisted of two lots of coal—No. 1 nut, designated Missouri 7 A, used in steaming tests 329 and 330 and washing test 152, and No. 2 nut, designated Missouri No. 7 B, used in steaming test 332 and washing test 153. This sample was also allotted to be used in washing test 154, but the coal was burned in the fire at the plant.

Two mine samples were taken for chemical analysis. Sample 2823 was cut 1,700 feet northeast of the shaft, where the coal measured 3 feet 3 inches in thickness. Sample 2824 was cut 1,750 feet south of the shaft, where the coal measured 3 feet in thickness.

CHEMICAL ANALYSES.

Missouri No. 7.

	Mine samples.		Car samples.			Steaming tests.[a]		
						A.		B.
			No. 1 nut.	Slack.	No. 2 nut.	329.	330.	332.
Laboratory number	2823	2824	2936	2942	2937	.....	.....	.....
Air-drying loss	14.60	13.70	14.50	15.20	9.70	.....	.....	.....
Proximate:								
Moisture	17.19	16.19	16.36	17.30	16.39	17.26	17.74	17.76
Volatile matter	34.05	31.25	29.12	26.43	29.01	32.11	32.65	32.00
Fixed carbon	39.48	39.87	35.01	32.89	34.42	40.32	39.26	39.95
Ash	9.28	12.69	19.51	23.38	20.18	10.31	10.35	10.29
Sulphur	2.76	3.03	3.53	2.94	3.12	3.27	3.24	3.19
Ultimate:								
Hydrogen	.....	.....	5.23	5.04	5.28	4.70	4.69	4.80
Carbon	.....	.....	49.44	45.41	49.03	68.20	68.11	67.97
Nitrogen	.....	.....	.87	.83	.91	1.20	1.20	1.26
Oxygen	.....	.....	21.42	22.40	21.48	9.49	9.48	9.58
Ash	.....	.....	.....	.....	.....	12.46	12.58	12.51
Sulphur	.....	.....	.....	.....	.....	3.95	3.94	3.88
Calorific value (as received):								
Determined, calories	5,888	.....	5,004	4,578	4,970	.....	.....	.....
Determined, B. t. u.	10,598	.....	9,007	8,240	8,946	.....	.....	.....
Calculated from ultimate analysis, calories	.....	.....	4,953	4,507	4,924	.....	.....	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	8,915	8,113	8,863	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Missouri No. 7 (washed nut).

	A.		B.
	Test 329.	Test 330.	Test 332.
Size as shipped	No. 1	No. 1	No. 2
Size as used:			
Over 1 inch ... per cent	47.0	46.3	21.4
½ inch to 1 inch ... do	21.6	23.2	43.6
¼ inch to ½ inch ... do	14.9	15.0	21.4
Under ¼ inch ... do	16.5	15.5	13.6
Duration of test ... hours	9.78	5.73	9.75
Heating value of coal ... B. t. u. per pound dry coal	12,659	12,643	12,469
Force of draft:			
Under stack damper ... inch water	0.60	0.71	0.71
Above fire ... do	.14	.13	.....
In ash pit (forced draft) ... do	.....	.....	.02
Furnace temperature ... °F	.....	.....	2,686
Dry coal used per square foot of grate surface per hour ... pounds	21.90	25.92	32.03
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.51	4.10	4.62
Percentage of rated horsepower of boiler developed	98.4	115.0	[a] 129.4
Water apparently evaporated per pound of coal as fired ... pounds	5.53	5.42	4.93
Water evaporated from and at 212 °F.:			
Per pound of coal as fired ... do	6.64	6.52	5.94
Per pound of dry coal ... do	8.03	7.92	7.22
Per pound of combustible ... do	9.32	9.29	8.36
Efficiency of boiler, including grate ... per cent	61.26	60.49	55.92
Coal as fired:			
Per indicated horsepower hour ... pounds	4.26	4.34	4.76
Per electrical horsepower hour ... do	5.26	5.36	5.88
Dry coal:			
Per indicated horsepower hour ... do	3.52	3.57	3.92
Per electrical horsepower hour ... do	4.35	4.41	4.84

[a] Test made for maximum capacity.

WASHING TESTS.

Missouri No. 7 (nut).

	Test 152 (A).	Test 153 (B).
Size as used	No. 1	No. 2
Jig used	Stewart.	Stewart.
Raw coal ... pounds	25,000	23,500
Washed coal ... do	21,470	18,600
Refuse ... do	3,530	4,900

Analyses.—Test 152: For raw coal analyses see page 171 (sample 2936). Washed coal: Moisture, 17.30; ash, 9.45; sulphur, 3.04. Test 153: For raw coal analyses see page 171 (sample 2937). Washed coal: Moisture, 19.70; ash, 11.05; sulphur, 3.07.

MISSOURI NO. 10.

Bituminous coal from the Bevier bed, at Bevier, Macon County, on the Chicago, Burlington and Quincy Railroad, was designated Missouri No. 10. The coal, as worked at a depth of 124 feet at this place, averages 4 feet 7 inches in thickness.

One sample, shipped under the direction of K. M. Way, consisted of screenings (through a ¾-inch shaking screen) and was used in steaming test 486 (on briquets) and briquetting tests 178†, 179, 241*, 245*, and 246*.

Two mine samples were taken for chemical analysis. Sample 4196 was taken 400 feet south of the shaft, where the coal measured 4 feet 3 inches in thickness. Sample 4197 was taken 2,500 feet west of shaft, where the coal measured 5 feet in thickness.

CHEMICAL ANALYSES.

Missouri No. 10.

	Mine samples.		Car sample.	Steaming test 486.[a]	Briquetting tests.[b]			
					178†.[c]	241*.	245*.	246*.
Laboratory No.	4196	4197	4257	4362	4515	4898	4876	4908
Air-drying loss	8.50	8.80	13.70	1.30	9.40	.....	.....	.....
Proximate:								
Moisture	15.26	15.41	15.23	4.51	11.03	8.91	7.79	7.75
Volatile matter	33.91	32.76	26.32	35.53	32.24	31.81	31.46	32.48
Fixed carbon	42.13	40.22	37.95	41.37	38.67	38.17	39.87	40.95
Ash	8.70	11.61	20.50	18.59	18.06	21.11	20.88	18.82
Sulphur	4.37	3.78	3.69	3.90	3.72	4.49	4.66	4.53
Ultimate:								
Hydrogen	.....	.....	5.02	4.34	.....	4.16	4.12	4.24
Carbon	.....	.....	49.41	64.29	.....	60.16	60.63	62.77
Nitrogen	.....	.....	.84	.91	.....	.84	.84	.91
Oxygen	.....	.....	20.54	6.91	.....	6.73	6.71	6.76
Ash	.....	.....	.....	19.47	.....	23.18	22.65	20.41
Sulphur	.....	.....	.....	4.08	.....	4.93	5.05	4.91
Calorific value determined (calories	.....	5,879	5,055	.....	.....	.....	.....	.....
(as received) ... B. t. u.	.....	10,582	9,099	.....	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.
[c] No ultimate analysis made.

STEAMING TEST.

Missouri No. 10 (briquets).

	Test 486.
Duration of test ..... hours..	9.63
Heating value of fuel ..... B. t. u. per pound dry fuel..	11,653
Force of draft:	
Under stack damper ..... inch water..	0.79
Above fire ..... do....	.15
Dry fuel used per square foot of grate surface per hour ..... pounds..	24.69
Equivalent water evaporated per square foot of water-heating surface per hour ..... do....	3.28
Percentage of rated horsepower of boiler developed	92.0
Water apparently evaporated per pound of fuel as fired ..... pounds..	5.25
Water evaporated from and at 212° F.:	
Per pound of fuel as fired ..... do....	6.36
Per pound of dry fuel ..... do....	6.66
Per pound of combustible ..... do....	8.41
Efficiency of boiler, including grate ..... per cent..	55.19
Fuel as fired:	
Per indicated horsepower hour ..... pounds..	4.45
Per electrical horsepower hour ..... do....	5.49
Dry fuel:	
Per indicated horsepower hour ..... do....	4.25
Per electrical horsepower hour ..... do....	5.24

Remarks.—Test made on briquets from tests 178† and 179. These burned freely, although the rate of combustion decreased as ash formed on the surface, particularly on the English briquets, where the ash could not be separated from the briquets; 2.4 per cent black smoke; ash heavy, gray, and fine; no clinker.

BRIQUETTING TESTS.

Missouri No. 10 (slack).

Tests 178†, 179, 241, 245*, 246*.*—Size as used: Over ¼ inch, 3.0 per cent; $\frac{1}{16}$ inch to ¼ inch, 10.2 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 17.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 21.2 per cent; through $\frac{1}{40}$ inch, 48.4 per cent. Equally satisfactory briquets were made with 7 and 8 per cent binder on English machine and 8 and 9 per cent on Renfrow machine. The large amount of clay present made briquets soft when warm, but very hard when cold, when fuel was worked with high moisture content. Tests 178† and 179 were made on coal from the same car and under greater pressure than in other tests. These briquets were harder, more cohesive, and made less slack in handling. All the briquets had rough surfaces and broke with ragged fracture. They were of a dull gray color, owing to the amount of clay present. For analyses of briquets see page 172 (those from test 179 under "Steaming test 486").

	Test 178†.	Test 179.	Test 241*.	Test 245*.	Test 246*
Details of manufacture:					
Machine used	Renf.	Eng.	Renf.	Renf.	Eng.
Temperature of briquets ..... °F..	176	185	149	149	149
Binder—					
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4543	4543	4806	4879	4879
Amount ..... per cent..	8	7	9	8.5	8
Weight of—					
Fuel briquetted ..... pounds..	42,000	5,000	66,000	176,000	10,000
Briquets, average ..... do....	0.476	4.43	0.481	0.523	3.91
Heat value per pound—					
Fuel as received ..... B. t. u..	9,099	9,099	9,081	9,081	9,081
Fuel as fired ..... do....	.....	11,128	10,082	10,262	10,580
Binder ..... do....	16,969	16,969	16,864	16,805	16,805
Drop test (1-inch screen):					
Held ..... per cent..	80.5	63.3	73.0	58.0	64.4
Passed ..... do....	19.5	36.7	27.0	42.0	35.6
Tumbler test (1-inch screen):					
Held ..... do....	94.0	90.9	91.5	87.0	64.2
Passed (fines) ..... do....	6.0	9.1	8.5	13.0	35.8
Fines through 10-mesh sieve ..... do....	99.0	80.9	95.0	90.3	50.0

BRIQUETTING TESTS—Continued

Missouri No. 10 (slack).

	Test 178†.	Test 179.	Test 241*.	Test 245*.	Test 246*.
Weathering test:					
Time exposed.....days..	19	19	.....	.....	.....
Condition.....	B.	C.	.....	.....	.....
Water absorption:					
In 19 days.....per cent..	14.5	7.6	.....	.....	.....
In 13 days.....do....	.....	.....	9.0	13.1	6.6
Average for first—					
5 days.....do....	1.94	.....	1.54	2.24	1.12
2 days.....do....	.....	2.2	.....	.....	.....
Specific gravity (apparent).....	1.172	1.238	1.207	1.108	1.248

Extraction analyses.

	Pitches.			Fuel.		Briquets.				
						Test 178†.	Test 179.	Test 241*.	Test 245*.	Test 246*.
Laboratory No.....	4543	4806	4879	4257	4803	4515	4362	4898	4876	4908
Air-drying loss.....per cent..	.....	.....	.....	13.70	10.30	9.40	1.30	.....	.....	.....
Extracted by CS_2:										
Air dried.....do....	.....	.....	.....	.54	.59	8.21	7.64	.....	.....	.....
As received.....do....	99.66	96.90	94.50	.47	.47	7.44	7.54	8.44	8.68	7.63
Pitch in briquets as received, per cent.....	.....	.....	.....	.....	.....	7.03	7.13	8.27	8.73	7.62

MONTANA.

MONTANA NO. 2.

Lignite from the Bridger bed at Fromberg, Carbon County, on the Northern Pacific Railway, was designated Montana No. 2. One sample, shipped under the supervision of N. H. Darton, was used in steaming test 470 and producer-gas test 149. Mine sample 3954 was taken by N. H. Darton.

CHEMICAL ANALYSES.

Montana No. 2.

	Mine sample.	Car sample.	Steaming test 470.[a]			Car sample.	Steaming test 470.[a]
Laboratory No...	3954	4234	.....	Ultimate:			
Air-drying loss....	.....	3.30	.....	Hydrogen.....		4.96	4.31
Proximate:				Carbon.....		58.96	63.36
Moisture.....	8.93	8.51	9.29	Nitrogen.....		1.10	1.18
Volatile matter	33.43	31.58	31.20	Oxygen.....		18.99	12.28
Fixed carbon..	46.92	44.52	42.96	Ash.....		.....	18.24
Ash.....	10.72	15.39	16.55	Sulphur.....		.....	.63
Sulphur.....	.61	.60	.57	Calorific value determined (as received).....	calories..	5,821	.....
					B. t. u...	10,478	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Montana No. 2.

		Test 470.
Size as used:		
Over 1 inch	per cent	38.2
½ inch to 1 inch	do	24.1
¼ inch to ½ inch	do	13.7
Under ¼ inch	do	24.0
Average diameter	inch	0.89
Duration of test	hours	6.50
Heating value of coal	B. t. u. per pound dry coal	11,257
Force of draft:		
Under stack damper	inch water	0.88
Above fire	do	.23
Dry coal used per square foot of grate surface per hour	pounds	26.51
Equivalent water evaporated per square foot of water-heating surface per hour	do	4.04
Percentage of rated horsepower of boiler developed		113.30
Water apparently evaporated per pound of coal as fired	pounds	5.75
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	6.93
Per pound of dry coal	do	7.64
Per pound of combustible	do	9.71
Efficiency of boiler, including grate	per cent	65.54
Coal as fired:		
Per indicated horsepower hour	pounds	4.08
Per electrical horsepower hour	do	5.04
Dry coal:		
Per indicated horsepower hour	do	3.70
Per electrical horsepower hour	do	4.57

PRODUCER-GAS TEST.

Montana No. 2.

Test 149.—Size as used: Over 1 inch, 51 per cent; ½ inch to 1 inch, 21 per cent; ¼ inch to ½ inch, 20 per cent; under ¼ inch, 18 per cent. Duration of test, 40 hours; average electrical horsepower, 188.9; average B. t. u. per cubic foot of gas, 147.5; total coal fired, 15,450 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.13	1.95	1.62
Developed at switch board	2.05	1.87	1.56
Per brake horsepower:			
Commercially available	1.81	1.66	1.38
Developed at engine	1.74	1.59	1.32
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.34	2.14	1.78
Developed at switchboard	2.25	2.06	1.71
Per brake horsepower:			
Commercially available	1.99	1.82	1.52
Developed at engine	1.91	1.75	1.45

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	13.2
Carbon monoxide (CO)	14.2
Hydrogen (H_2)	16.0
Methane (CH_4)	2.9
Nitrogen (N_2)	25.9
Oxygen (O_2)	.2
Ethylene (C_2H_4)	.6

[a] For analysis of fuel used see page 174 (sample 4234).

MONTANA NO. 3.

Lignite from the Bridger bed at Bridger, Carbon County, on the Northern Pacific Railway, was designated Montana No. 3. One sample, shipped under the supervision of N. H. Darton, was used in steaming test 477 and producer-gas test 150. Two mine samples, 3955 and 3956, were taken by N. H. Darton.

CHEMICAL ANALYSES.

Montana No. 3.

	Mine samples.		Car sample.	Steaming test 477.[a]
Laboratory No.	3955	3956	4271	.....
Air-drying loss	.....	.....	3.10	.....
Proximate:				
Moisture	8.47	8.70	8.56	9.2
Volatile matter	31.47	34.03	32.36	32.2
Fixed carbon	41.88	49.07	45.69	44.9
Ash	18.18	8.20	13.39	13.6
Sulphur	.84	.63	.54	.6
Ultimate:				
Hydrogen	.....	.....	5.06	4.47
Carbon	.....	.....	60.39	65.70
Nitrogen	.....	.....	1.06	1.16
Oxygen	.....	.....	19.56	13.00
Ash	.....	.....	.....	15.01
Sulphur	.....	.....	.....	.66
Calorific value determined (as received) calories	.....	.....	5,936	.....
Calorific value determined (as received) B. t. u.	.....	.....	10,685	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Montana No. 3.

	Test 477.
Size as used:	
Over 1 inch ... per cent	52.9
½ inch to 1 inch ... do	21.6
¼ inch to ½ inch ... do	10.9
Under ¼ inch ... do	14.6
Average diameter ... inches	1.46
Duration of test ... hours	8.97
Heating value of coal ... B. t. u. per pound dry coal	11,628
Force of draft:	
Under stack damper ... inch water	0.86
Above fire ... do	.14
Dry coal used per square foot of grate surface per hour ... pounds	26.98
Equivalent water evaporated per square foot of water-heating surface per hour ... do	4.11
Percentage of rated horsepower of boiler developed	115.2
Water apparently evaporated per pound of coal as fired ... pounds	5.75
Water evaporated from and at 212° F.:	
Per pound of coal as fired ... do	6.92
Per pound of dry coal ... do	7.63
Per pound of combustible ... do	9.32
Efficiency of boiler, including grate ... per cent	63.37
Coal as fired:	
Per indicated horsepower hour ... pounds	4.09
Per electrical horsepower hour ... do	5.04
Dry coal:	
Per indicated horsepower hour ... do	3.71
Per electrical horsepower hour ... do	4.58

PRODUCER-GAS TEST.

Montana No. 3.

Test 150.—Duration of test, 49 hours. Average electrical horsepower, 199.6; average B. t. u. per cubic foot of gas, 181.5; total coal fired, 15,950 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.69	1.55	1.32
Developed at switch board	1.63	1.49	1.27
Per brake horsepower:			
Commercially available	1.44	1.31	1.12
Developed at engine	1.39	1.27	1.08
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.80	1.65	1.41
Developed at switch board	1.74	1.59	1.36
Per brake horsepower:			
Commercially available	1.53	1.40	1.20
Developed at engine	1.48	1.35	1.15

Analysis of gas by volume.[a]

Carbon doxide (CO_2)	8.0
Carbon monoxide (CO)	23.2
Hydrogen (H_2)	15.9
Methane (CH_4)	3.3
Nitrogen (N_2)	49.2
Ethylene (C_2H_4)	.4

NEW MEXICO.

NEW MEXICO NO. 3.

Bituminous coal from Van Houten, Colfax County, on the Atchison, Topeka and Santa Fe Railway, was designated New Mexico No. 3. The coal, as worked from an outcrop at this place, averages 6 feet 6 inches in thickness.

Three kinds of coal were shipped from this mine under the supervision of J. S. Burrows: New Mexico No. 3 A consisted of run-of-mine coal used in steaming test 396 and producer-gas test 121. New Mexico No. 3 B consisted of 10 tons of lump and was used in steaming tests 389 and 391; also, together with equal portions of washed New Mexico No. 4 B and No. 5, in coking test 152 and cupola tests 98 and 130. New Mexico No. 3 C consisted of 40 tons of slack, and was used in steaming test 392 (on washed coal); washing test 168; and coking tests 148 and 149 (on washed coal). At this mine coal that passes through a ¾-inch screen is called "slack," and that passing over the ¾-inch screen is graded as "lump."

Two mine samples taken for chemical analysis. Sample 3221 was taken 2,000 feet northwest of the drift mouth, where the coal measured 6 feet 11 inches in thickness. Sample 3222 was taken 3,000 feet from the drift mouth, where the coal measured 6 feet 11 inches in thickness.

[a] For analysis of fuel used, see page 176 (sample 4271).

CHEMICAL ANALYSES.

New Mexico No. 3.

	Mine samples.		Car samples.			Steaming tests.[a]			
						A.	B.		C.
			A.	C.	B.	396.	389.	391.	392.
Laboratory No.	3221	3222	3295	3307	3308				
Air-drying loss	1.00	2.00	2.00	3.00	1.40				
Proximate:									
Moisture	2.50	3.48	3.45	4.36	2.75	2.82	3.01	2.47	4.77
Volatile matter	35.47	33.02	32.00	32.21	33.19	32.72	32.61	32.99	33.10
Fixed carbon	52.90	50.58	47.82	47.51	48.54	47.56	47.05	47.63	49.90
Ash	9.13	12.92	16.67	15.92	15.52	16.90	17.33	16.91	12.23
Sulphur	.72	.64	.73	.83	.64	.72	.72	.67	.71
Ultimate:									
Hydrogen			4.95	4.79	4.84	4.72	4.55	4.58	4.83
Carbon			66.19	65.96	67.70	68.45	67.93	68.43	72.14
Nitrogen			1.23	1.18	1.18	1.28	1.19	1.19	1.26
Oxygen			10.23	11.32	10.12	7.42	7.72	7.77	8.17
Ash						17.39	17.87	17.34	12.85
Sulphur						.74	.74	.69	.75
Calorific value (as received):									
Determined, calories	7,293		6,607	6,618	6,759				
Determined, B. t. u.	13,127		11,893	11,912	12,166				
Calculated from ultimate analysis, calories			6,629	6,509	6,715				
Calculated from ultimate analysis, B. t. u.			11,932	11,716	12,087				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

New Mexico No. 3.

	A.	B.		C.
	Test 396.	Test 389.	Test 391.	Test 392 (w.).
Size as shipped	r. o. m.	l.	l.	s.
Size as used:				
Over 1 inch ... per cent	14.8	30.6	34.5	5.6
½ inch to 1 inch ... do	23.2	27.1	27.9	27.9
⅛ inch to ½ inch ... do	22.2	18.3	16.8	31.3
Under ⅛ inch ... do	39.8	24.0	20.8	35.2
Duration of test ... hours	10.0	10.0	10.0	9.37
Heating value of coal ... B. t. u. per pound dry coal	12,301	12,213	12,301	13,059
Force of draft:				
Under stack damper ... inch water	0.60	0.54	0.57	0.64
Above fire ... do	.22	.18	.21	.22
Furnace temperature ... °F.	2,333	2,225	2,432	2,420
Dry coal used per square foot of grate surface per hour, pounds	23.48	20.91	23.82	24.56
Equivalent water evaporated per square foot of water-heat-surface per hour ... pounds	3.86	3.51	4.09	4.25
Percentage of rated horsepower of boiler developed	108.2	98.5	114.8	119.2
Water apparently evaporated per pound of coal as fired, pounds	6.84	7.02	7.18	7.08
Water evaporated from and at 212 °F.:				
Per pound of coal as fired ... pounds	8.00	8.16	8.40	8.26
Per pound of dry coal ... do	8.23	8.42	8.61	8.68
Per pound of combustible ... do	10.36	10.54	10.66	10.16
Efficiency of boiler, including grate ... per cent	64.61	66.58	67.59	64.19
Coal as fired:				
Per indicated horsepower hour ... pounds	3.54	3.46	3.37	3.42
Per electrical horsepower hour ... do	4.36	4.28	4.16	4.23
Dry coal:				
Per indicated horsepower hour ... do	3.44	3.36	3.28	3.26
Per electrical horsepower hour ... do	4.24	4.15	4.06	4.02

PRODUCER-GAS TEST.

New Mexico No. 3 A (run of mine).

Test 121.—Duration of test, 50 hours; average electrical horsepower, 198.4; average B. t. u. per cubic foot of gas, 155.1; total coal fired, 12,850 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.37	1.32	1.05
Developed at switch board	1.30	1.25	.99
Per brake horsepower:			
Commercially available	1.17	1.12	.90
Developed at engine	1.10	1.06	.85
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.47	1.42	1.13
Developed at switch board	1.39	1.34	1.07
Per brake horsepower:			
Commercially available	1.25	1.21	.96
Developed at engine	1.18	1.14	.91

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.62	Carbon dioxide (CO_2)	9.2
Volatile matter	31.56	Carbon monoxide (CO)	20.5
Fixed carbon	45.19	Hydrogen (H_2)	14.5
Ash	19.63	Methane (CH_4)	2.0
Sulphur	.72	Nitrogen (N_2)	53.4
		Ethylene (C_2H_4)	.4

WASHING AND COKING TESTS.

New Mexico No. 3.

Washing test 168 (coal C, slack).—Jig used, Stewart. Raw coal, 43,000 pounds; washed coal, 38,000 pounds; refuse 5,000 pounds.

Coking tests.

		3 C (s.).		3 B (l.), 4 B (s.), and 5 (r. o. m.).
		Test 148 (raw).	Test 149 (w.).	Test 152 (w.).
Size as used		f. c.	f. c.	f. c.
Duration of test	hours	52	48	48
Coal charged	pounds	12,120	11,710	12,000
Coke produced	do	7,655	7,233	7,596
	per cent	63.16	61.77	63.30
Breeze produced	pounds	410	360	328
	per cent	3.38	3.07	2.73
Total yield	do	66.54	64.84	66.03

Remarks.—Test 148: Light gray and silvery; good heavy coke; ash high. Test 149: Light gray and silvery; good heavy coke; ash reduced by washing, but still high. Test 152: Light gray and silvery; good, strong, heavy coke; good ring, breakage, and cell structure.

Analyses.

	Washing test 168.		Coking test 148.		Coking test 149.		Coking test 152.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	4.36	6.01	3.68	0.76	5.74	0.88	5.13	0.69
Volatile matter	32.21	.....	33.06	.67	33.02	1.51	33.88	1.48
Fixed carbon	47.51	.....	48.94	78.14	48.99	80.42	50.06	82.18
Ash	15.92	12.43	14.32	20.43	12.25	17.19	10.93	15.65
Sulphur	.83	.71	.78	.71	.72	.65	.69	.63

Cupola tests of coke made from New Mexico Nos. 3 B, 4 B, and 5 coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
98	152	1.91	7	99.9	Coke	210	55	55	55	55	430
					Pig iron	630	405	405	405	405	2,250
					Scrap	210	135	135	135	135	750
130	152	1.91	7	99.9	Coke	200	58	58	57	57	430
					Pig iron	600	413	413	412	412	2,250
					Scrap	200	138	138	137	137	750

[a] Phosphorus in coke, 0.0348 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
98	1.48 p. m.	7	11	1,162	325	1,487	29	3,076	4.31	7.50	1,288	85
130	3.18 p. m.	7	10	1,778	252	2,030	28	4,511	6.51	7.03	759	118

LADLE RECORD.

Ladle No.	Test 98.		Test 130.		Ladle No.	Test 98.		Test 130.	
	Pounds.	Time (p. m.).	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).	Pounds.	Time (p. m.).
1	83	2.07	94	3.34	13	55	2.24	94	3.45
2	86	2.07½	52	3.34½	14	64	2.24½	84	3.45½
3	39	2.08	97	3.38	15	53	2.25	82	3.46
4	78	2.15	88	3.38½	16	68	2.27	24	3.47
5	79	2.15½	79	3.39	17	42	2.27½	86	3.49½
6	86	2.16	109	3.39½	18	66	2.28	99	3.50
7	58	2.18	83	3.40½	19	.....	.....	84	3.51
8	66	2.18½	82	3.41	20	.....	.....	64	3.51½
9	70	2.19	91	3.42	21	.....	.....	86	3.53½
10	52	2.21	95	3.42½	22	.....	.....	25	3.54
11	61	2.22	75	3.43½	23	.....	.....	57	3.55
12	56	2.22½	48	3.44					

Remarks.—Test 98: Iron very hot and fluid. Large quantities of slag closed up tuyeres after sixteenth ladle.

NEW MEXICO NO. 4.

Bituminous coal from Brilliant, Colfax County, on the Atchison, Topeka and Santa Fe Railway, was designated New Mexico No. 4. The coal, as worked from the outcrop at this place, averages 5 feet in thickness.

Two samples of coal were taken from these mines for testing purposes under the supervision of J. S. Burrows. New Mexico No. 4 A consisted of run-of-mine coal and was used in making steaming tests 397 (raw) and 398 (washed), producer-gas test 122, and washing test 174. New Mexico No. 4 B consisted of slack coal through a 1¼-inch perforated screen, and was used in making steaming test 395, washing test 170, coking tests 150 (raw) and 151 (washed), and cupola test 119. Mixed with New Mexico No. 3 B and No. 5 (equal portions, washed), No. 4 B was also used in coking test 152 (see p. 179) and cupola tests 98 and 130 (see p. 180).

Two mine samples were taken for chemical analysis. Sample 3228 was taken 475 feet southwest of the drift mouth, where the coal measured 5 feet 8 inches in thickness. Sample 3229 was taken 800 feet south of the drift mouth, where the coal measured 4 feet 3 inches in thickness.

CHEMICAL ANALYSES.

New Mexico No. 4.

	Mine samples.		Car samples.		Steaming tests.[a]		
			A.	B.	A.		B.
					397.	398.	395.
Laboratory No	3228	3229	3331	3315	.....	.....	.....
Air-drying loss	1.00	1.30	1.40	1.70	.....	.....	.....
Proximate:							
Moisture	2.19	2.67	2.78	3.38	2.30	3.86	3.37
Volatile matter	35.95	36.25	34.31	34.63	34.59	34.06	34.70
Fixed carbon	50.75	51.26	48.34	48.45	48.53	50.68	48.18
Ash	11.11	9.82	14.57	13.54	14.58	11.40	13.75
Sulphur	.57	.58	.61	.61	.60	.63	.62
Ultimate:							
Hydrogen	.....	.....	5.06	5.13	4.89	5.07	4.91
Carbon	.....	.....	68.51	68.67	70.54	73.07	70.90
Nitrogen	.....	.....	1.51	1.50	1.56	1.61	1.55
Oxygen	.....	.....	9.74	10.55	7.48	7.73	7.77
Ash	.....	.....	.....	.....	.61	.66	.64
Sulphur	.....	.....	.....	.....	14.92	11.86	14.23
Calorific values (as received):							
Determined, calories	7,257	.....	6,830	6,914	.....	.....	.....
Determined, B. t. u	13,063	.....	12,294	12,445	.....	.....	.....
Calculated from ultimate analysis, calories	.....	.....	6,873	6,875	.....	.....	.....
Calculated from ultimate analysis, B. t. u	.....	.....	12,371	12,375	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

New Mexico No. 4.

	A.		B.
	Test 397.	Test 398 (w.).	Test 395.
Size as shipped	r. o. m.	r. o. m.	s.
Size as used:			
Over 1 inch ... per cent	21.3	17.4	1.7
½ inch to 1 inch ... do	23.2	21.6	17.8
¼ inch to ½ inch ... do	18.8	25.2	27.4
Under ¼ inch ... do	36.7	35.8	53.1
Duration of test ... hours	10.0	10.07	10.08
Heating value of coal ... B. t. u. per pound dry coal	12,659	13,149	12,847
Force of draft:			
Under stack damper ... inch water	0.64	0.64	0.61
Above fire ... do	.25	.25	.22
Furnace temperature ... ° F.	2,336	2,534	2,285
Dry coal used per square foot of grate surface per hour ... pounds	22.76	21.92	21.33
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.71	3.86	3.59
Percentage of rated horsepower of boiler developed	103.9	108.1	100.6
Water apparently evaporated per pound of coal as fired ... pounds	6.79	7.23	6.96
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	7.97	8.47	8.14
Per pound of dry coal ... do	8.16	8.81	8.43
Per pound of combustible ... do	9.84	10.17	10.10
Efficiency of boiler, including grate ... per cent	62.25	64.70	63.37
Coal as fired:			
Per indicated horsepower hour ... pounds	3.55	3.34	3.47
Per electrical horsepower hour ... do	4.38	4.12	4.29
Dry coal:			
Per indicated horsepower hour ... do	3.47	3.21	3.35
Per electrical horsepower hour ... do	4.28	3.96	4.14

PRODUCER-GAS TEST.

New Mexico No. 4 A (run of mine).

Test 122.—Duration of test, 50 hours. Average electrical horsepower, 189.5. Average B. t. u. per cubic foot of gas, 135.3. Total coal fired, 13,110 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.48	1.44	1.24
Developed at switchboard	1.38	1.35	1.16
Per brake horsepower:			
Commercially available	1.25	1.22	1.05
Developed at engine	1.18	1.15	0.99
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.62	1.58	1.36
Developed at switchboard	1.52	1.48	1.28
Per brake horsepower:			
Commercially available	1.38	1.34	1.16
Developed at engine	1.29	1.26	1.08

Analyses.

Coal.		*Gas by volume.*	
Moisture	2.42	Carbon dioxide (CO_2)	10.6
Volatile matter	34.82	Carbon monoxide (CO)	17.0
Fixed carbon	49.23	Hydrogen (H_2)	12.6
Ash	13.53	Methane (CH_4)	2.0
Sulphur	.63	Nitrogen (N_2)	57.2
		Ethylene (C_2H_4)	.6

WASHING AND COKING TESTS.

New Mexico No. 4.

Washing tests.

	Test 174 (A).	Test 170 (B).
Size as shipped	r. o. m.	s.
As used	cr. to 2″	s.
Jig used	Stewart.	Stewart.
Raw coal ... pounds	20,000	24,000
Washed coal ... do	16,275	21,000
Refuse ... do	3,725	3,000

Coking tests (B).

	Test 150 (raw).	Test 151 (w.).
Size as used	f. c.	f. c.
Duration of test ... hours	49	43
Coal charged ... pounds	11,790	11,430
Coke produced ... do	7,610	6,986
Coke produced ... per cent	64.55	61.12
Breeze produced ... pounds	362	307
Breeze produced ... per cent	3.07	2.69
Total yield ... do	67.62	63.81

Remarks.—Test 150: Light gray and silvery; good heavy coke; ash high. Test 151: Light gray and silvery; good heavy coke; ash reduced by washing.

Analyses.

	Washing test 174 (A).		Washing test 170 (B).		Coking test 150 (B).		Coking test 151 (B).	
	Raw.	Washed.	Raw.	Washed.	Coal.	Coke.	Coal.	Coke.
Moisture	2.78	3.71	3.38	5.97	3.69	1.10	5.52	1.39
Volatile matter	34.31	.....	34.63	.....	34.62	.94	35.29	.85
Fixed carbon	48.34	.....	48.45	.....	47.83	78.48	49.87	83.66
Ash	14.57	11.39	13.54	9.41	13.86	19.48	9.32	14.10
Sulphur	.61	.58	.61	.65	.66	.58	.67	.60

Cupola test of coke made from New Mexico No. 4 B coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
119	151	1.92	7	98.61	Coke	200	58	58	57	57	430
					Pig iron	600	413	413	412	412	2,250
					Scrap	200	138	138	137	137	750

[a] Phosphorus in coke, 0.0946 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
119	8.57 a. m.	7	6	2,210	351	2,561	31	4,957	7.30	9.23	162	79

Cupola test of coke made from New Mexico No. 4 B coal (washed)—Continued.

LADLE RECORD.

Ladle No.	Test 119.		Ladle No.	Test 119.	
	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).
1	95	9.12	14	83	9.25
2	53	9.12½	15	76	9.26
3	96	9.16	16	103	9.26½
4	94	9.16½	17	81	9.27
5	28	9.17	18	88	9.28
6	88	9.19	19	106	9.28½
7	102	9.20	20	86	9.29
8	70	9.20½	21	70	9.29½
9	89	9.21	22	101	9.31
10	66	9.23	23	82	9.32
11	86	9.23½	24	65	9.32½
12	85	9.24	25	69	9.33
13	106	9.24½	26	142	9.34

NEW MEXICO NO. 5.

Bituminous coal from Blossburg, Colfax County, on the Atchison, Topeka and Santa Fe Railway, was designated New Mexico No. 5. The coal, as worked from the outcrop at this place, averages 7 feet 6 inches in thickness.

This sample was run-of-mine coal loaded under the supervision of J. S. Burrows, and was used in making steaming test 387, producer-gas test 120, washing test 167, coking tests 146 (raw) and 147 (washed), and cupola test 120. Mixed with New Mexico No. 3 B and No. 4 B (equal portions, washed), it was also used in coking test 152 (see p. 179) and cupola tests 98 and 130 (see p. 180).

Two mine samples were taken for chemical analysis. Sample 3226 was taken 5,300 feet north of the slope, where the coal measured 7 feet in thickness. Sample 3227 was taken 4,200 feet southwest of the slope, where the coal measured 7 feet 8 inches in thickness.

CHEMICAL ANALYSES.

New Mexico No. 5.

	Mine samples.		Car sample.	Steaming test 387.[a]
Laboratory No.	3226	3227	3294	.....
Air-drying loss	1.20	1.20	1.40	.....
Proximate:				
Moisture	2.25	2.31	2.72	2.32
Volatile matter	33.19	33.01	31.85	31.80
Fixed carbon	52.19	51.58	50.86	50.23
Ash	12.37	13.10	14.57	15.65
Sulphur	.75	.66	.69	.79
Ultimate:				
Hydrogen	.....	.....	4.88	4.65
Carbon	.....	.....	69.96	70.94
Nitrogen	.....	.....	1.17	1.19
Oxygen	.....	.....	8.73	6.39
Ash	.....	.....	.....	16.02
Sulphur	.....	.....	.....	.81
Calorific value (as received):				
Determined, calories	7,239	.....	6,966	.....
Determined, B. t. u.	13,030	.....	12,539	.....
Calculated from ultimate analysis, calories	.....	.....	6,974	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	12,553	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

New Mexico No. 5 (run of mine).

		Test 387.
Size as used:		
Over 1 inch	per cent	21.2
½ inch to 1 inch	do	19.9
¼ to ½ inch	do	20.8
Under ¼ inch	do	38.1
Duration of test	hours	10.07
Heating value of coal	B. t. u. per pound dry coal	12,721
Force of draft:		
Under stack damper	inch water	0.58
Above fire	do	.21
Furnace temperature	°F	2,371
Dry coal used per square foot of grate surface per hour	pounds	21.11
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.54
Percentage of rated horsepower of boiler developed		99.13
Water apparently evaporated per pound of coal as fired	pounds	7.0
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.19
Per pound of dry coal	do	8.39
Per pound of combustible	do	10.23
Efficiency of boiler, including grate	per cent	63.69
Coal as fired:		
Per indicated horsepower hour	pounds	3.45
Per electrical horsepower hour	do	4.26
Dry coal:		
Per indicated horsepower hour	do	3.37
Per electrical horsepower hour	do	4.16

PRODUCER-GAS TEST.

New Mexico No. 5 (run of mine).

Test 120.—Duration of test, 45 hours. Average electrical horsepower, 197.2. Average B. t. u. per cubic foot of gas, 159.6. Total coal fired, 12,500 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.49	1.47	1.24
Developed at switchboard	1.41	1.38	1.17
Per brake horsepower:			
Commercially available	1.27	1.25	1.05
Developed at engine	1.20	1.18	0.99
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.60	1.57	1.33
Developed at switchboard	1.51	1.48	1.25
Per brake horsepower:			
Commercially available	1.36	1.34	1.13
Developed at engine	1.29	1.26	1.06

Analyses.

Coal.		*Gas by volume.*	
Moisture	1.79	Carbon dioxide (CO_2)	8.6
Volatile matter	31.32	Carbon monoxide (CO)	21.4
Fixed carbon	51.40	Hydrogen (H_2)	14.6
Ash	15.49	Methane (CH_4)	2.2
Sulphur	.66	Nitrogen (N_2)	52.7
		Ethylene (C_2H_4)	.5

WASHING AND COKING TESTS.

New Mexico No. 5 (run of mine).

Washing test 167.—Size as used, crushed to 2 inches; jig used, Stewart; raw coal, 15,000 pounds; washed coal, 13,300 pounds; refuse, 1,700 pounds.

Coking tests.

	Test 146 (raw)	Test 147 (w.)
Size as used	f. c.	f. c.
Duration of test ... hours	56	50
Coal charged ... pounds	11,810	11,770
Coke produced ... do	7,500	7,650
Coke produced ... per cent	63.51	65.00
Breeze produced ... pounds	320	280
Breeze produced ... per cent	2.71	2.38
Total yield ... do	66.22	67.38

Remarks.—Test 146: Light gray color; good heavy coke; high ash. Test 147: Light gray and silvery; good heavy coke; ash reduced by washing, but still high.

Analyses.

	Washing test 167.		Coking test 146.		Coking test 147.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	2.72	4.68	3.05	1.04	4.23	0.99
Volatile matter	31.85	.....	31.96	1.44	32.25	.84
Fixed carbon	50.86	.....	49.71	76.93	51.79	81.38
Ash	14.57	11.87	15.28	20.59	11.73	16.79
Sulphur	.09	.91	.76	.86	.89	.76

Cupola test of coke made from New Mexico No. 5 coal (washed).

CHARGE.

Cupola test No.	Coke.[a] Test No.	Coke.[a] Specific gravity.	Coke.[a] Ratio, iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
120	147	1.91	7	99.9	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750

[a] Phosphorus in coke, 0.001 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure. On at	Blast pressure. Maximum.	Iron running in	Weight of iron. Poured.	Weight of iron. Additional melted.	Weight of iron. Total.	Melting. Time.	Melting. Rate per hour.	Melting. Ratio iron to coke.	Melting. Loss.	Recovered. Iron.	Recovered. Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
120	2.17 p. m.	7	10	1,354	124	1,478	28	3,167	4.58	7.40	1,300	107

Cupola test of coke made from New Mexico No. 5 coal (washed)—Continued.

LADLE RECORD.

Ladle No.	Test 120.		Ladle No.	Test 120.	
	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).
1	93	2.34	10	99	2.43½
2	50	2.34½	11	96	2.44½
3	57	2.39	12	101	2.47
4	107	2.39½	13	90	2.48
5	99	2.40	14	56	2.47
6	43	2.40½	15	92	2.52½
7	83	2.41	16	32	2.53
8	92	2.42	17	69	2.55
9	95	2.43			

Remarks.—Test 120: Iron hot and fluid.

OHIO.

OHIO NO. 10.

Bituminous coal from bed No. 5, at Mineral City, Tuscarawas County, was designated Ohio No. 10. The coal, as worked from the outcrop at this place, averages 3 feet 5 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of lump coal over a 1¼-inch bar screen, and was used in steaming test 469 and producer-gas test 142.

Two mine samples were taken for chemical analysis. Sample 3968 was taken 7,000 feet southeast of the opening, where the coal measured 3 feet 3 inches in thickness. Sample 3969 was taken 6,600 feet southeast of the opening, where the coal measured 3 feet 7 inches in thickness.

CHEMICAL ANALYSES.

Ohio No. 10.

	Mine samples.		Car sample.	Steaming test 469.[a]
Laboratory No.	3968	3969	4059	.....
Air-drying loss	1.30	1.10	2.30	.....
Proximate:				
Moisture	5.61	4.46	4.49	4.10
Volatile matter	36.25	39.89	40.55	39.55
Fixed carbon	49.42	47.11	47.43	47.54
Ash	8.72	8.54	7.53	8.81
Sulphur	2.89	3.73	2.93	3.60
Ultimate:				
Hydrogen	.....	.....	5.68	5.30
Carbon	.....	.....	69.64	71.28
Nitrogen	.....	.....	1.29	1.32
Oxygen	.....	.....	12.93	9.15
Ash	.....	.....	.....	9.19
Sulphur	.....	.....	.....	3.76
Calorific value determined (as received) calories	.....	7,136	7,199	.....
Calorific value determined (as received) B. t. u.	.....	12,845	12,958	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Ohio No. 10.

		Test 469.
Size as used:		
Over 1 inch	per cent	58.3
½ inch to 1 inch	do	13.9
¼ inch to ½ inch	do	9.1
Under ¼ inch	do	18.7
Average diameter	inches	1.30
Duration of test	hours	10.02
Heating value of coal	B. t. u. per pound dry coal	13,291
Force of draft:		
Under stack damper	inch water	0.81
Above fire	do	.19
Furnace temperature	°F.	2,877
Dry coal used per square foot of grate surface per hour	pounds	22.91
Equivalent water evaporated per square foot of water-heating surface per hour	do	4.25
Percentage of rated horsepower of boiler developed		119.1
Water apparently evaporated per pound of coal as fired	pounds	7.38
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.90
Per pound of dry coal	do	9.28
Per pound of combustible	do	10.39
Efficiency of boiler, including grate	per cent	67.43
Coal as fired:		
Per indicated horsepower hour	pounds	3.18
Per electrical horsepower hour	do	3.92
Dry coal:		
Per indicated horsepower hour	do	3.05
Per electrical horsepower hour	do	3.76

PRODUCER-GAS TEST.

Ohio No. 10 (lump).

Test 142.—Size as used: Over 1 inch, 64 per cent; ½ inch to 1 inch, 17 per cent; ¼ inch to ½ inch, 8 per cent; under ¼ inch, 11 per cent. Duration of test, 50 hours. Average electrical horsepower, 199.0. Average B. t. u. per cubic foot of gas, 165.6. Total coal fired, 12,650 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.32	1.27	1.15
Developed at switch board	1.27	1.22	1.11
Per brake horsepower:			
Commercially available	1.12	1.08	.98
Developed at engine	1.08	1.04	.94
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.40	1.35	1.22
Developed at switch board	1.35	1.30	1.18
Per brake horsepower:			
Commercially available	1.19	1.15	1.04
Developed at engine	1.15	1.10	1.00

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.05	Carbon dioxide (CO_2)	9.4
Volatile matter	39.28	Carbon monoxide (CO)	20.7
Fixed carbon	47.75	Hydrogen (H_2)	14.2
Ash	8.92	Methane (CH_4)	2.6
Sulphur	3.02	Nitrogen (N_2)	52.6
		Ethylene (C_2H_4)	.5

OHIO NO. 11.

Bituminous coal from bed No. 8 at Flushing, Belmont County, on the Baltimore and Ohio Railroad, was designated Ohio No. 11. The coal, as worked at a depth of 89 feet at this place, averages 4 feet 10 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of lump coal over a 1¼-inch screen and was used in steaming tests 474 and 475 and producer-gas test 145.

Two mine samples were taken for chemical analysis. Sample 3985 was taken 2,000 feet west of the shaft, where the coal measured 4 feet 8¼ inches in thickness. Sample 3986 was taken 1,500 feet southwest of the shaft, where the coal measured 5 feet 1 inch in thickness.

CHEMICAL ANALYSES.

Ohio No. 11.

	Mine samples.		Car sample.	Steaming tests.[a]	
				474.	475.
Laboratory No	3985	3986	4157	.....	.....
Air-drying loss	1.70	1.90	1.60	.....	.....
Proximate:					
Moisture	3.96	4.13	3.44	3.56	3.53
Volatile matter	38.09	39.22	36.04	37.86	37.33
Fixed carbon	48.91	48.69	47.58	47.91	47.92
Ash	9.04	7.96	12.94	10.67	11.22
Sulphur	4.25	4.12	4.32	4.03	5.24
Ultimate:					
Hydrogen	.....	.....	4.81	4.74	4.63
Carbon	.....	.....	66.64	71.23	69.70
Nitrogen	.....	.....	1.17	1.25	1.22
Oxygen	.....	.....	10.12	7.54	7.39
Ash	.....	.....	.....	11.06	11.63
Sulphur	.....	.....	.....	4.18	5.43
Calorific value determined (as received) calories	.....	7,271	6,826	.....	.....
Calorific value determined (as received) B. t. u.	.....	13,088	12,287	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Ohio No. 11.

	Test 474.	Test 475.
Size as used:		
Over 1 inch ... per cent	65.7	71.7
½ inch to 1 inch ... do	16.8	12.9
¼ inch to ½ inch ... do	7.6	6.7
Under ¼ inch ... do	9.9	8.7
Average diameter ... inches	1.72	2.06
Duration of test ... hours	9.23	9.28
Heating value of coal ... B. t. u. per pound dry coal	13,115	12,890
Force of draft:		
Under stack damper ... inch water	0.78	0.77
Above fire ... do	.20	.19
Furnace temperature ... °F	2,748	2,893
Dry coal used per square foot of grate surface per hour ... pounds	20.84	20.67
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.65	3.66
Percentage of rated horsepower of boiler developed	102.4	102.5
Water apparently evaporated per pound of coal as fired ... pounds	7.04	7.08
Water evaporated from and at 212° F.:		
Per pound of coal as fired ... do	8.47	8.55
Per pound of dry coal ... do	8.79	8.86
Per pound of combustible ... do	10.14	10.21
Efficiency of boiler, including grate ... per cent	64.72	66.38

STEAMING TESTS—Continued.

Ohio No. 11.

	Test 474.	Test 475.
Coal as fired:		
Per indicated horsepower hour.....pounds..	3.34	3.31
Per electrical horsepower hour.....do....	4.12	4.08
Dry coal:		
Per indicated horsepower hour.....do....	3.22	3.19
Per electrical horsepower hour.....do....	3.97	3.94

PRODUCER-GAS TEST.

Ohio No. 11 (lump).

Test 145.—Size as used, over 1 inch, 66 per cent.; ½ inch to 1 inch, 14 per cent.; ¼ inch to ½ inch, 7 per cent. Under ¼ inch, 13 per cent. Duration of test, 50 hours. Average electrical horsepower, 199.5. Average B. t. u. per cubic foot of gas, 165.200. Total coal fired, 13,850 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available.....	1.45	1.40	1.21
Developed at switchboard.....	1.39	1.34	1.16
Per brake horsepower:			
Commercially available.....	1.23	1.19	1.03
Developed at engine.....	1.18	1.14	.99
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available.....	1.55	1.50	1.30
Developed at switchboard.....	1.49	1.44	1.24
Per brake horsepower:			
Commercially available.....	1.32	1.27	1.10
Developed at engine.....	1.26	1.22	1.06

Analysis of gas by volume.[a]

Carbon dioxide (CO_2).....	9.0
Carbon monoxide (CO).....	20.2
Hydrogen (H_2).....	15.3
Methane (CH_4).....	2.7
Nitrogen (N_2).....	52.3
Ethylene (C_2H_4).....	0.5

OHIO NO. 12.

Bituminous coal from bed No. 8, at Bellaire, Belmont County, was designated Ohio No. 12. The coal, as worked from the outcrop at this place, averages 5 feet 5 inches in thickness.

One sample, shipped under the supervision of K. M. Way, consisted of run-of-mine coal and was used in steaming test 483, producer-gas tests 146 and 147, washing test 193, and coking test 180.

Two mine samples were taken for chemical analysis. Sample 3987 was taken at a face where the coal measured 5 feet 6¼ inches in thickness. Sample 3988 was taken at a face where the coal measured 5 feet 4½ inches in thickness.

[a] For analysis of fuel used see page 189 (sample 4157).

CHEMICAL ANALYSES.

Ohio No. 12.

	Mine samples.		Car samples.		Steaming test 483.[a]
Laboratory No	3987	3988	4151	4178	.....
Air-drying loss	1.20	1.10	2.60	1.30	.....
Proximate:					
Moisture	3.32	3.10	4.14	2.97	3.55
Volatile matter	40.80	40.76	39.30	37.61	38.35
Fixed carbon	49.11	50.11	47.18	49.45	48.37
Ash	6.77	6.03	9.38	9.97	9.73
Sulphur	3.55	3.42	3.96	3.65	4.00
Ultimate:					
Hydrogen	.....	.....	5.19	5.14	4.91
Carbon	.....	.....	69.58	70.21	72.32
Nitrogen	.....	.....	1.20	1.23	1.24
Oxygen	.....	.....	10.69	9.80	7.29
Ash	.....	.....	.....	.....	10.09
Sulphur	.....	.....	.....	.....	4.15
Calorific value determined (as received) calories	.....	.....	7,152	7,185	.....
Calorific value determined (as received) B. t. u.	.....	.....	12,874	12,933	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Ohio No. 12.

		Test 483.
Size as used:		
Over 1 inch	per cent	23.8
½ inch to 1 inch	do	25.7
¼ inch to ½ inch	do	20.5
Under ¼ inch	do	30.0
Average diameter	inch	0.72
Duration of test	hours	9.05
Heating value of coal	B. t. u. per pound dry coal	13,381
Force of draft:		
Under stack damper	inch water	.85
Above fire	do	.21
Dry coal used per square foot of grate surface per hour	pounds	22.98
Equivalent water evaporated per square foot of water-heating surface per hour	do	4.20
Percentage of rated horsepower of boiler developed		117.6
Water apparently evaporated per pound of coal as fired	pounds	7.28
Water evaporated from and at 212° F.:		
Per pound of coal as fired	pounds	8.81
Per pound of dry coal	do	9.14
Per pound of combustible	do	10.40
Efficiency of boiler, including grate	per cent	65.96
Coal as fired:		
Per indicated horsepower hour	pounds	3.21
Per electrical horsepower hour	do	3.96
Dry coal:		
Per indicated horsepower hour	pounds	3.09
Per electrical horsepower hour	do	3.82

PRODUCER-GAS TESTS.

Ohio No. 12 (run of mine).

		Test 146.	Test 147.
Size as used:			
Over 1 inch	per cent	62	52
½ inch to 1 inch	do	21	18
¼ inch to ½ inch	do	10	11
Under ¼ inch	do	7	19
Duration of test	hours	34	50
Average electrical horsepower		198.8	198.6
Average B. t. u. per cubic foot of gas		164.8	164.6
Total coal fired	pounds	10,650	14,350

PRODUCER-GAS TESTS—Continued.

Ohio No. 12 (run of mine).

	Test 146.			Test 147.		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	1.65	1.60	1.44	1.51	1.45	1.28
Developed at switchboard	1.58	1.53	1.37	1.45	1.39	1.23
Per brake horsepower:						
Commercially available	1.40	1.36	1.22	1.28	1.23	1.09
Developed at engine	1.34	1.30	1.17	1.23	1.18	1.05
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	1.77	1.72	1.54	1.62	1.56	1.38
Developed at switchboard	1.69	1.64	1.47	1.56	1.50	1.33
Per brake horsepower:						
Commercially available	1.50	1.46	1.31	1.38	1.33	1.18
Developed at engine	1.43	1.39	1.25	1.32	1.27	1.13

Analyses.

	Test 146.	Test 147.		Test 146.	Test 147.
Coal.			*Gas by volume.*		
Moisture	2.97	3.82	Carbon dioxide (CO_2)	9.4	9.3
Volatile matter	37.61	37.77	Carbon monoxide (CO)	19.8	19.9
Fixed carbon	49.45	47.42	Hydrogen (H_2)	15.7	15.2
Ash	9.97	10.99	Methane (CH_4)	2.9	2.5
Sulphur	3.65	3.39	Nitrogen (N_2)	51.8	52.6
			Ethylene (C_2H_4)	.4	.5

WASHING TEST.

Ohio No. 12.

Test 193.—Duration of test, 50 minutes. Size as used, through 2-inch screen. Jig used, Stewart; speed, 35 r. p. m.; stroke, 6 inches. Raw coal, 6.7 tons; washed coal, 5.1 tons, 76 per cent; refuse, 1.6 tons, 24 per cent.

Analyses.

Sample tested.	Laboratory No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4151	4.14	9.38	.....	3.96	.....
Washed coal, test 193	4519	6.85	6.19	33	3.60	9
Refuse	.....	5.78	19.91	.....	6.62	.....

Float and sink tests.

No. of test.	Sizes as used (inch).	Specific gravity of solu- used.	Percentage of float.		Sink (per cent).	Analyses.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	¾	1.35	.....	77	23	5.12	45	3.23	18
2	¾	1.40	.....	89	11	6.43	32	3.63	8
3	¾	1.45	.....	92	8	6.78	28	3.88	2
4	¾	1.52	.....	94	6	7.31	22	3.98	.....
On refuse (float):[a]									
1	.....	1.35	39	9.35	.....	5.75	.....	3.67	.....
2	.....	1.41	57	13.29	.....	6.42	.....	4.04	.....
3	.....	1.45	59	14.09	.....	9.12	.....	5.26	.....
4	.....	1.53	81	19.30	.....	10.17	.....	4.97	.....

[a] Loss of good coal, 9 per cent.

COKING TEST.

Ohio No. 12 (run of mine).

Test 180.—Size as used, washed, finely crushed. Duration of test, 45 hours. Coal charged, 9,270 pounds. Coke produced, 5,190 pounds; 55.99 per cent. Breeze produced, 223 pounds; 2.41 per cent. Total yield, 58.40 per cent. Light gray, with some silvery deposit of carbon; sulphur high.

Analyses.

	Coal.	Coke.
Moisture	5.19	0.73
Volatile matter	39.04	.51
Fixed carbon	48.36	87.96
Ash	6.41	10.80
Sulphur	3.63	3.08

PENNSYLVANIA.

PENNSYLVANIA NO. 7.[a]

Bituminous coal from a mine 3 miles north of Ligonier, Westmoreland County, on the Ligonier Valley Railroad, was designated "Pennsylvania No. 7."

This sample, consisting of run-of-mine coal loaded under the supervision of J. S. Burrows, was used in making steaming test 307.

[a] For other tests of coal from this mine, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, pp. 176-178.

CHEMICAL ANALYSES.

Pennsylvania No. 7.

	Steaming test 307.[a]		Steaming test 307.[a]
Proximate:		Ultimate:	
Moisture	5.80	Hydrogen	4.37
Volatile matter	21.79	Carbon	74.41
Fixed carbon	58.78	Nitrogen	1.53
Ash	13.68	Oxygen	2.86
Sulphur	2.22	Ash	14.47
		Sulphur	2.36

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Pennsylvania No. 7 (run of mine).

		Test 307.
Size as used:		
Over 1 inch	per cent	16.8
½ inch to 1 inch	do	21.7
¼ inch to ½ inch	do	19.5
Under ¼ inch	do	42.0
Duration of test	hours	10.07
Heating value of coal	B. t. u. per pound dry coal	13,455
Force of draft:		
Under stack damper	inch water	0.54
Above fire	do	.13
Furnace temperature	°F.	2,220
Dry coal used per square foot of grate surface per hour	pounds	16.35
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.03
Percentage of rated horsepower of boiler developed		85.0
Water apparently evaporated per pound of coal as fired	pounds	7.34
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.76
Per pound of dry coal	do	9.29
Per pound of combustible	do	11.16
Efficiency of boiler, including grate	per cent	66.68
Coal as fired:		
Per indicated horsepower hour	pounds	3.23
Per electrical horsepower hour	do	3.99
Dry coal:		
Per indicated horsepower hour	do	3.04
Per electrical horsepower hour	do	3.76

PENNSYLVANIA NO. 11.

Bituminous coal from the Pittsburg bed at Charleroi, Washington County, on the Pennsylvania Railroad, was designated "Pennsylvania No. 11." The coal, as worked from the outcrop at this place, averages 5 feet 6 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in producer-gas test 129, coking test 159, and cupola tests 143 and 161.

Two mine samples were taken for chemical analysis. Sample 3421 was taken 4,000 feet southwest of the opening, where the coal measured 5 feet 5¾ inches in thickness. Sample 3422 was taken 4,000 feet northwest of the opening, where the coal measured 5 feet 6¾ inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 11.

	Mine samples.		Car sample.		Mine samples.		Car sample.
Laboratory No	3421	3422	3532	Ultimate:			
Air-drying loss	1.20	1.30	0.60	Hydrogen			5.13
Proximate:				Carbon			76.86
Moisture	2.50	2.56	1.95	Nitrogen			1.44
Volatile matter	34.65	34.55	34.07	Oxygen			8.10
Fixed carbon	57.51	55.94	56.69	Ash			
Ash	5.34	6.95	7.29	Sulphur			
Sulphur	1.14	2.27	1.18	Calorific value determined (as received). calories.	7,859		7,653
				Calorific value determined (as received). B. t. u.	14,146		13,775

PRODUCER-GAS TEST.

Pennsylvania No. 11 (run of mine).

Test 129.—Duration of test, 50 hours. Average electrical horsepower, 170.7. Average B. t. u. per cubic foot of gas, 146.4. Total coal fired, 12,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower-hour (pounds).			
Per electrical horsepower:			
Commercially available	1.53	1.50	1.39
Developed at switchboard	1.43	1.40	1.30
Per brake horsepower:			
Commercially available	1.30	1.27	1.18
Developed at engine	1.22	1.19	1.10
Equivalent used by producer plant.			
Per electrical horsepower:			
Commercially available	1.66	1.63	1.51
Developed at switchboard	1.55	1.52	1.41
Per brake horsepower:			
Commercially available	1.41	1.38	1.28
Developed at engine	1.32	1.29	1.20

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	10.4
Carbon monoxide (CO)	18.5
Hydrogen (H_2)	16.3
Methane (CH_4)	2.0
Nitrogen (N_2)	52.6
Ethylene (C_2H_4)	.2

COKING TEST.

Pennsylvania No. 11 (run of mine).

Test 159.—Size as used, raw, finely crushed. Duration of test, 41 hours. Coal charged, 12,040 pounds. Coke produced, 8,100 pounds; 67.28 per cent. Breeze produced, 296 pounds; 2.46 per cent. Total yield, 69.74 per cent. Light-gray color. Good coke.

Analysis.

	Coal.	Coke.
Moisture	2.20	0.52
Volatile matter	33.18	.97
Fixed carbon	55.46	85.02
Ash	9.16	13.49
Sulphur	1.36	1.19
Phosphorus		.0307

[a] *For analyses of fuel used, see above (sample 3532).*

Cupola tests of coke made from Pennsylvania No. 11 coal.

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
143	159	1.92	7	97.22	Coke	200	58	58	57	57	430
					Pig iron	800	550	550	550	550	3,000
161	159	1.92	6	93.75	Coke	220	70	70	70	70	500
					Pig iron	880	530	530	530	530	3,000

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
143	3.08 p. m.	7	10	1,636	278	1,914	34	3,378	5.33	4.63	947	71
161	1.58 p. m.	7	10	2,054	542	2,596	28	5,563	6.12	4.40	272	76

LADLE RECORD.

Ladle No.	Test 143.		Test 161.		Ladle No.	Test 143.		Test 161.	
	Pounds.	Time (p. m.)	Pounds.	Time (p. m.)		Pounds.	Time (p. m.)	Pounds.	Time (p. m.)
1	68	3.22	93	2.12	13	80	3.39	73	2.26
2	72	3.24	110	2.13	14	93	3.43	64	2.28
3	104	3.26	80	2.16	15	85	3.43½	86	2.28½
4	90	3.27	82	2.16½	16	93	3.44	132	2.29
5	90	3.32	125	2.17	17	78	3.48	66	2.30
6	101	3.32½	68	2.22	18	100	3.49	94	2.30½
7	87	3.33	73	2.22½	19	28	3.52	134	2.31
8	93	3.35	59	2.23	20			61	2.33
9	99	3.35½	109	2.23½	21			83	2.33½
10	87	3.36	137	2.24	22			99	2.34
11	86	3.38	70	2.25	23			37	2.36
12	102	3.38½	119	2.25½					

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (pounds)	Silicon.		Manganese.		Sulphur.		Content of coke combined with iron melted (per cent).
			Per cent.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	
143	Pig iron		2.12	40.58	0.178	3.407	0.059	1.1293	4.83
	Melted iron:								
	Amount		1.85	35.41	.111	2.124	.070	1.3398	
	Gain or loss		−12.74	− 5.17	−37.66	−1.283	+ .011	+ .2105	
	Coke	366					1.19	4.3554	
161	Pig iron		2.10	54.52	.163	4.231	.098	2.5441	7.57
	Melted iron:								
	Amount		1.74	45.17	.113	2.933	.113	2.9335	
	Gain or loss		−17.15	− 9.35	−30.68	−1.298	+ .015	+ .3894	
	Coke	432					1.19	5.1408	

Remarks.—Test 143: Pig iron used from car 27633. Iron hot. Test 161: Pig iron used from car 131943. Iron cold.

PENNSYLVANIA NO. 12.

Bituminous coal from the Pittsburg bed at Acheson, Washington County, on the Baltimore and Ohio Railroad, was designated Pennsylvania No. 12. The coal, as worked from the outcrop at this place, averages 5 feet 1 inch in thickness.

One sample, shipped under the supervision of John W. Groves, consisting of run-of-mine coal, was used in producer-gas test 143, washing test 179, coking tests 161 and 162, and cupola tests 145, 146, 151, 152, 153, and 154.

Two mine samples were taken for chemical analysis. Sample 3441 was taken 1,100 feet west of the opening, where the coal measured 5 feet 3¼ inches in thickness. Sample 3442 was taken 1,600 feet southwest of the opening, where the coal measured 4 feet 11 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 12 (run of mine).

	Mine samples.		Car sample.			Mine samples.		Car sample.
Laboratory No	3441	3442	4098	Ultimate:				
Air-drying loss	1.40	2.00	0.70	Hydrogen				4.81
Proximate:				Carbon				74.37
Moisture	2.60	3.21	1.96	Nitrogen				1.45
Volatile matter	32.46	32.27	30.55	Oxygen				7.93
Fixed carbon	59.31	58.64	58.24	Calorific value determined (as received)	calories	7,880		7,568
Ash	5.63	5.88	9.25		B. t. u.	14,184		13,622
Sulphur	1.19	1.22	2.19					

PRODUCER-GAS TEST.

Pennsylvania No. 12 (run of mine).

Test 143.—Size as used: Over 1 inch, 20 per cent; ½ to 1 inch, 17 per cent; ¼ inch to ½ inch, 18 per cent; under ¼ inch, 45 per cent. Duration of test, 28 hours. Average electrical horsepower, 195.3. Average B. t. u. per cubic foot of gas, 147.5. Total coal fired, 6,100 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.16	1.14	1.03
Developed at switchboard	1.12	1.09	.99
Per brake horsepower:			
Commercially available	.99	.97	.88
Developed at engine	.95	.93	.84
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.28	1.26	1.14
Developed at switchboard	1.23	1.21	1.09
Per brake horsepower:			
Commercially available	1.09	1.07	.97
Developed at engine	1.05	1.03	.93

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	10.8
Carbon monoxide (CO)	16.6
Hydrogen (H_2)	14.9
Methane (CH_4)	2.4
Nitrogen (N_2)	54.8
Ethylene (C_2H_4)	.5

[a] *For analysis of fuel used see above (sample 4098).*

WASHING AND COKING TESTS.

Pennsylvania No. 12 (run of mine).

Washing test 179.—Size as used, 2-inch. Jig used, Stewart. Raw coal, 21,200 pounds. Washed coal, 16,900 pounds; 80 per cent. Refuse, 4,300 pounds; 20 per cent.

Coking tests.

		Test 161 (raw).	Test 162 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	47	48
Coal charged	pounds	11,950	12,140
Coke produced	do	7,885	8,100
	per cent	65.98	66.72
Breeze produced	pounds	286	257
	per cent	2.39	2.12
Total yield	do	68.37	68.84

Remarks.—Test 161: Light gray and silvery; fair coke. Test 162: Light gray and silvery; good coke. Ash and sulphur reduced by washing.

Analyses.

	Washing test 179.		Coking test 161.		Coking test 162.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	1.96	4.63	2.46	0.69	4.50	0.52
Volatile matter	30.55	.....	31.28	.29	31.35	1.28
Fixed carbon	58.24	.....	56.70	86.29	57.66	89.13
Ash	9.25	6.40	9.56	12.73	6.49	9.07
Sulphur	2.19	1.39	2.03	1.66	1.40	1.11
Phosphorus	.....	.....	.....	.0184	.....	.0087

Cupola tests of coke made from Pennsylvania No. 12 coal.

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
145	161	1.97	7	97.22	Coke	210	55	55	55	55	430
					Pig iron	840	540	540	540	540	3,000
146	162 (w.)	1.95	7	99.9	Coke	210	55	55	55	55	430
					Pig iron	840	540	540	540	540	3,000
151	161	1.97	6	96.53	Coke	220	70	70	70	70	500
					Pig iron	880	530	530	530	530	3,000
152	161	1.97	8	98.61	Coke	200	44	44	44	43	375
					Pig iron	800	550	550	550	550	3,000
153	162 (w.)	1.95	6	99.9	Coke	210	73	73	72	72	500
					Pig iron	840	540	540	540	540	3,000
154	162 (w.)	1.95	8	97.22	Coke	220	38¾	38¾	38¾	38¾	375
					Pig iron	880	530	530	530	530	3,000

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
145	3.13 p. m.	7	11	1,439	1,139	2,578	41	7,031	7.41	9.17	147	82
146	11.14 a. m.	7	12	1,831	205	2,036	34	3,590	6.08	4.07	812	95
151	3.29 p. m.	7	11	2,382	256	2,638	35	4,522	6.26	5.03	211	79
152	10.39 a. m.	7	8	1,841	450	2,291	33	4,165	7.61	4.10	586	74
153	2.56 p. m.	7	11	2,352	120	2,472	36	3,917	5.96	4.66	388	85
154	10.57 a. m.	7	9	2,162	355	2,517	31	4,872	8.50	5.80	309	79

Cupola tests of coke made from Pennsylvania No. 12 coal—Continued.

LADLE RECORD.

Ladle No.	Test 145.		Test 146.		Test 151.		Test 152.		Test 153.		Test 154.	
	Lbs.	Time (p. m.).	Lbs.	Time (a. m.).	Lbs.	Time (p. m.).	Lbs.	Time (a. m.).	Lbs.	Time (p. m.).	Lbs.	Time (a. m.).
1	106	3.32	100	11.30	55	3.43	97	10.53	95	3.11	92	11.15
2	112	3.32½	97	11.32	98	3.46	96	10.59	29	3.11½	133	11.15½
3	103	3.35	100	11.33	55	3.46½	110	10.59½	97	3.14	78	11.16
4	91	3.35½	101	11.34	94	3.49	91	11.00	95	3.14½	122	11.16½
5	100	3.36	88	11.38	103	3.49½	95	11.04	108	3.18	93	11.19
6	97	3.37	110	11.38½	96	3.50	101	11.04½	108	3.18½	93	11.19½
7	89	3.38	69	11.39	90	3.53	112	11.05	108	3.19	93	11.20
8	87	3.38½	151	11.42	101	3.53½	118	11.05½	102	3.23	135	11.22
9	106	3.39	111	11.42½	105	3.54	100	11.07	108	3.23½	95	11.22½
10	59	3.52	112	11.43	77	3.59	107	11.07½	112	3.24	109	11.23
11	50	3.52½	103	11.48	107	3.59½	106	11.08	99	3.25	101	11.25
12	68	3.59	163	11.48½	145	4.00	89	11.10	100	3.25½	73	11.25½
13	72	4.00	95	11.49	106	4.00½	104	11.10½	100	3.26	86	11.26
14	82	4.01	96	11.55	100	4.01	107	11.11	101	3.29	113	11.28
15	65	4.02	114	11.55½	99	4.03	105	11.14	100	3.29½	73	11.28½
16	59	4.04	89	11.56	117	4.03½	110	11.14½	115	3.30	93	11.29
17	70	4.04½	60	11.58	83	4.04	111	11.15	90	3.32	118	11.31
18	23	4.05	72	12.00	76	4.08	57	11.19	99	3.34	73	11.31½
19					107	4.08½	25	11.20	109	3.34½	100	11.32
20					105	4.09			85	3.35	114	11.35
21					109	4.10			98	3.40	70	11.35½
22					71	4.10½			102	3.40½	88	11.36
23					108	4.11			103	3.41	17	11.37
24					109	4.11½			89	3.43		
25					66	4.15						

SILICON, MANGANESE, ETC.

Cupola test No.	Materials.	Amount used (pounds).	Silicon.		Manganese.		Sulphur.		
			Per cent.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	Content of coke combined with iron melted (per ct.)
145	Pig iron		2.12	54.65	0.178	4.589	0.059	1.5216	4.35
	Melted iron:								
	Amount		1.89	48.72	.133	3,429	.069	1.7788	
	Gain or loss		—10.85	—5.93	—25.28	—1.160	+.010	+.2572	
	Coke	356					1.66	5.9096	
146	Pig iron		2.12	43.16	.178	3.624	.059	1.2012	11.20
	Melted iron:								
	Amount		1.84	37.46	.141	2.871	.080	1.6288	
	Gain or loss		—13.21	—5.70	—20.78	—.753	+.021	+.4276	
	Coke	344					1.11	3.8184	
151	Pig iron		2.12	55.93	.178	4.696	.059	1.5564	5.94
	Melted iron:								
	Amount		1.91	50.39	.123	3.245	.078	2.0576	
	Gain or loss		—9.90	—5.54	—30.90	—1.451	+.019	+.5012	
	Coke	429					1.66	8.4414	
152	Pig iron		2.12	48.57	.178	4.078	.059	1.3517	4.92
	Melted iron:								
	Amount		1.86	42.61	.130	2.978	.070	1.6037	
	Gain or loss		—12.28	—5.96	—26.97	—1.100	+.011	+.2520	
	Coke	308					1.66	5.1128	
153	Pig iron		2.12	52.41	.178	4.400	.059	1.4585	15.27
	Melted iron:								
	Amount		1.78	44.00	.218	3.164	.088	2.1754	
	Gain or loss		—16.05	—8.41	—28.09	—1.236	+.029	+.7169	
	Coke	423					1.11	4.69.53	
154	Pig iron		2.12	53.36	.178	4.480	.059	1.4850	11.13
	Melted iron:								
	Amount		1.81	45.56	.136	3.423	.074	1.8626	
	Gain or loss		—14.62	—7.80	—23.59	—1.057	+.016	+.3776	
	Coke	304					1.11	3.3744	

Remarks.—Pig iron used from car 27633. Test 145: Iron hot. Blast off 19 minutes; melting too fast to handle. Tests 146, 151, 152, and 153: Iron hot. Test 154: Temperature of iron medium.

PENNSYLVANIA NO. 13.

Bituminous coal from the Freeport bed at Creighton, Allegheny County, on the Pennsylvania Railroad, was designated Pennsylvania No. 13. The coal, as worked from the outcrop at this place, averages 5 feet 10 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in producer-gas tests 136 and 140.

Two mine samples were taken for chemical analysis. Sample 3437 was taken 4,800 feet northwest of the opening, where the coal measured 6 feet 1 inch in thickness. Sample 3438 was taken 5,500 feet northwest of the opening, where the coal measured 5 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 13.

	Mine samples.		Car sample.			Mine samples.		Car sample
Laboratory No.	3437	3438	3879	Ultimate:				
Air-drying loss	1.00	1.30	1.40	Hydrogen				5.11
Proximate:				Carbon				70.25
Moisture	2.53	2.93	2.65	Nitrogen				1.21
Volatile matter	33.99	34.02	33.02	Oxygen				8.11
Fixed carbon	54.50	55.52	51.17	Calorific value determined (as received)	calories	7,420		7,120
Ash	8.98	7.53	13.16		B. t. u.	13,356		12,816
Sulphur	2.21	1.87	2.16					

PRODUCER-GAS TESTS.

Pennsylvania No. 13 (run of mine).

		Test 136.	Test 140.
Size as used:			
Over 1 inch	per cent	65	49
½ inch to 1 inch	do	15	24
¼ inch to ½ inch	do	8	12
Under ¼ inch	do	12	15
Duration of test	hours	50	50
Average electrical horsepower		193.2	196.5
Average B. t. u. per cubic foot of gas		153.0	144.9
Total coal fired	pounds	12,600	11,750

	Test 136.			Test 140.		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available	1.36	1.33	1.15	1.25	1.23	1.08
Developed at switchboard	1.30	1.27	1.10	1.20	1.18	1.03
Per brake horsepower:						
Commercially available	1.16	1.13	.98	1.06	1.04	.92
Developed at engine	1.11	1.08	.93	1.02	1.00	.38
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available	1.49	1.45	1.25	1.36	1.34	1.19
Developed at switchboard	1.42	1.38	1.20	1.30	1.28	1.12
Per brake horsepower:						
Commercially available	1.26	1.23	1.06	1.16	1.14	1.00
Developed at engine	1.21	1.18	1.02	1.10	1.09	.95

Analyses.

	Test 136.	Test 140.		Test 136.	Test 140.
Coal.			*Gas by volume.*		
Moisture	2.65	1.65	Carbon dioxide (CO_2)	11.0	11.1
Volatile matter	33.02	33.06	Carbon monoxide (CO)	17.2	11.5
Fixed carbon	51.17	53.22	Hydrogen (H_2)	14.9	12.6
Ash	13.16	12.07	Methane (CH_4)	2.4	2.1
Sulphur	2.16	1.80	Nitrogen (N_2)	54.0	57.1
			Ethylene (C_2H_4)	.5	.6

PENNSYLVANIA NO. 15.

Bituminous coal from the "Miller" or B bed at Wehrum, Indiana County, on the Pennsylvania Railroad, was designated Pennsylvania No. 15. The coal, as worked at a depth of 187 feet at this place, averages 3 feet 10 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal, and was used in steaming tests 467 (on briquets), 472, and 473; producer-gas test 144; washing test 188; coking tests 185 and 188; and briquetting tests 176 and 184† (mixed with Rhode Island No. 1, see p. 223).

Two mine samples were taken for chemical analysis. Sample 4026 was taken 2,000 feet northeast of the shaft, where the coal measured 4 feet 2½ inches in thickness. Sample 4027 was taken 1,900 feet southwest of the shaft, where the coal measured 3 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 15.

	Mine samples.		Car samples.		Steaming tests.[a]			Briquetting test 184†.[b]
					472.	473.	467.	
Laboratory No	4026	4027	4082	4104	.....	.....	.....	4913
Air-drying loss	3.30	2.40	2.80	2.10	.....	.....	.....	.....
Proximate:								
Moisture	3.83	2.84	3.13	2.57	1.88	2.45	3.90	0.74
Volatile matter	19.03	17.47	17.61	18.09	17.60	17.55	23.35	15.96
Fixed carbon	67.89	71.42	69.45	69.01	69.06	70.56	64.65	69.71
Ash	9.25	8.27	9.81	10.33	11.46	9.44	8.10	13.59
Sulphur	4.57	3.11	3.77	3.97	5.37	3.87	3.11	2.61
Ultimate:								
Hydrogen	.....	.....	4.62	4.43	4.13	4.31	4.35	3.05
Carbon	.....	.....	76.41	75.89	75.63	78.83	78.71	77.48
Nitrogen	.....	.....	1.14	1.16	1.15	1.21	1.09	.49
Oxygen	.....	.....	4.25	4.22	1.94	2.00	4.18	2.65
Ash	.....	.....	.....	.....	11.68	9.68	8.43	13.70
Sulphur	.....	.....	.....	.....	5.47	3.97	3.24	2.63
Calorific value determined (as received)	calories	7,821	7,664	7,618	.....	.....	.....	.....
	B. t. u.	14,079	13,795	13,712	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Pennsylvania No. 15 (run of mine).

	Test 472.	Test 473.	Test 467.
Size as used:			
Over 1 inch ... per cent	8.2	4.6	See p. 204.
½ inch to 1 inch ... do	11.1	6.9	
¼ inch to ½ inch ... do	19.2	13.9	
Under ¼ inch ... do	61.5	74.6	
Average diameter ... inch	0.41	0.31	
Duration of test ... hours	8.75	9.77	8.87
Heating value of fuel ... B. t. u. per pound of dry fuel	13,729	14,240	14,258
Force of draft:			
Under stack damper ... inch water	0.81	0.82	0.76
Above fire ... do	.27	.23	.17
Furnace temperature ... °F	2,512	2,615	2,753
Dry fuel used per square foot of grate surface per hour ... pounds	16.87	17.24	17.63
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.00	3.25	3.53
Percentage of rated horsepower of boiler developed	84.2	91.2	99.00
Water apparently evaporated per pound of fuel as fired ... pounds	7.27	7.65	7.98
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	8.76	9.22	9.65
Per pound of dry fuel ... do	8.93	9.45	10.04
Per pound of combustible ... do	10.57	10.85	11.30
Efficiency of boiler, including grate ... per cent	62.81	64.09	68.00
Fuel as fired:			
Per indicated horsepower hour ... pounds	3.23	3.07	2.93
Per electrical horsepower hour ... do	3.99	3.79	3.62
Dry fuel:			
Per indicated horsepower hour ... do	3.17	2.99	2.82
Per electrical horsepower hour ... do	3.91	3.69	3.48

Remarks.—Test 467 on Renfrow briquets from test 176, which burned freely with short flame, 5.4 per cent black smoke, and very hot fire; briquets coking well and throwing off fragments of coke in ash during combustion; 39 per cent clinker, thin, metallic, red and black, brittle when cold; ash of dark gray color, looked like coke.

PRODUCER-GAS TEST.

Pennsylvania No. 15 (lump).

Test 144.—Size as used: Over 1 inch, 7 per cent; ½ inch to 1 inch, 14 per cent; ¼ inch to ½ inch, 18 per cent; under ¼ inch, 61 per cent. Duration of test, 24 hours. Average electrical horsepower, 191.8. Average B. t. u. per cubic foot of gas, 144.4. Total coal fired, 5,700 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.29	1.26	1.12
Developed at switchboard	1.24	1.21	1.08
Per brake horsepower:			
Commercially available	1.10	1.07	.96
Developed at engine	1.05	1.03	.92
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.43	1.39	1.25
Developed at switchboard	1.37	1.34	1.20
Per brake horsepower:			
Commercially available	1.22	1.18	1.06
Developed at engine	1.17	1.14	1.02

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	10.7
Carbon monoxide (CO)	17.2
Hydrogen (H_2)	15.8
Methane (CH_4)	2.2
Nitrogen (N_2)	53.8
Ethylene (C_2H_4)	.3

[a] For analyses of fuel used see p. 201 (sample 4104).

WASHING TESTS.

Pennsylvania No. 15.

Test 188.—Duration of test, 2 hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 r. p. m.; stroke, 2½ inches. Raw coal, 20.37 tons; washed coal, 15.25 tons, 75 per cent; refuse, 5.12 tons, 25 per cent.

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4082	3.13	9.81	.....	3.77	.....
Washed coal, test 188	4597	6.45	5.38	45	1.53	59
Refuse	.....	5.78	47.18	.....	19.78	.....

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analysis.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	½	1.35	.....	72	28	5.47	44	1.30	66
2	½	1.41	.....	78	22	5.27	46	1.45	62
3	½	1.45	.....	80	20	5.54	43	1.54	59
4	½	1.52	.....	81	19	6.26	36	1.71	55
On refuse (float): [a]									
1	.....	1.35	11.80	2.95	.....	4.95	.....	1.71	.....
2	.....	1.41	13.20	3.30	.....	6.50	.....	2.13	.....
3	.....	1.46	14.50	3.64	.....	7.65	.....	2.29	.....
4	.....	1.51	17.20	4.30	.....	8.15	.....	2.88	.....

[a] Figures indicate that finer crushing is advantageous. Loss of "good coal" in the refuse will not exceed 2 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal.

COKING TESTS.

Pennsylvania No. 15 (run of mine, washed).

		Test 185.	Test 188.
Size as used		f. c.	r. o. m.
Duration of test	hours	61	54
Coal charged	pounds	9,750	12,460
Coke produced	do	5,779	8,144
	per cent	59.27	65.36
Breeze produced	pounds	262	332
	per cent	2.69	2.66
Total yield	do	61.96	68.02

Remarks.—Test 185: Dull-gray color; soft dense coke; high sulphur. Test 188: Light gray and silvery; much better than coke from finely ground coal; high sulphur.

Analyses.

	Test 185.		Test 188.	
	Coal.	Coke.	Coal.	Coke.
Moisture	7.19	0.56	4.53	0.57
Volatile matter	17.86	.32	18.56	.55
Fixed carbon	69.57	91.10	70.63	90.23
Ash	5.38	8.02	6.28	8.65
Sulphur	1.63	1.46	1.85	1.54

BRIQUETTING TESTS.

Pennsylvania No. 15 (run of mine.)

Test 176.—Size as used: Over ¼ inch, 2.2 per cent; $\frac{1}{10}$ inch to ¼ inch, 6 per cent; $\frac{1}{20}$ inch, to $\frac{1}{10}$ inch, 12 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 19 per cent; through $\frac{1}{40}$ inch, 60.8 per cent. This test, with 7 per cent binder, gave satisfactory briquets, which were tough and easily handled without breaking when warm, but brittle when cold. Broke with characteristic smooth glossy fracture, hard surface, and sharp edges. For analyses of briquets see page 201 (steaming test 467).

Test 184†.—Size as used: Over ¼ inch, 0.8 per cent; $\frac{1}{10}$ inch, to ¼ inch, 7 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 15 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 22.2 per cent; through $\frac{1}{40}$ inch, 55 per cent. Pennsylvania No. 15 was mixed with an equal portion of Rhode Island No. 1 (run of mine) in this test. Excellent briquets were made with 6.25 per cent binder on the Renfrow machine. Although the pitch used had a low melting point, the briquets handled well from the machine, and piled without sticking. The outer surface was very hard and smooth, and broke without crumbling, giving a smooth fracture and sharp edges. For analyses of briquets see page 201.

	Test 176.	Test 184†.		Test 176.	Test 184†.
Details of manufacture:			Tumbler test (1-inch screen):		
Machine used	Renf.	Renf.	Held ... per cent	70.5	93.0
Temperature of briquets. °F.	185	185	Passed (fines) ... do	29.5	7.0
Binder—			Fines through 10-mesh sieve ... per cent	85.0	91.4
Kind	w. g. p.	w. g. p.	Weathering test:		
Laboratory No. (see p. 40)	4553	4543	Time exposed ... days	53	11
Amount ... per cent	7	6.25	Condition	A.	A.
Weight of—			Water absorption:		
Fuel briquetted. pounds	8,000	10,000	In 19 days ... per cent	22.0	.....
Briquets, average ... do	0.420	0.5	In 16 days ... do	.....	13.3
Heat value per pound—			Average for first—		
Fuel as received ... B. t. u.	13,712	[a]13,712 [b]10,996	4 days ... do	4.05	.....
Fuel as fired ... do	13,702	12,793	5 days ... do	.....	1.90
Binder	16,969	16,969	Specific gravity (apparent)	1.043	1.275
Drop test (1-inch screen):					
Held ... per cent	50.5	68.5			
Passed ... do	49.5	31.5			

[a] Pennsylvania No. 15. [b] Rhode Island No. 1 (see p. 223).

Extraction analyses.

	Pitch.	Fuel.		Briquets.	
		Pa. No. 15.	R. I. No. 1.	Test 176.	Test 184†.
Laboratory No	4543	4104	3141	.....	4913
Air-drying loss ... per cent	.....	2.10	3.40	2.80	0.03
Extracted by CS_2:					
Air-dried ... do	.....	.79	.02	5.89	6.27
As received ... do	99.66	.77	.02	5.72	6.25
Pitch in briquets, as received ... do	.....	.....	.....	5.02	5.91

PENNSYLVANIA NO. 16.

Bituminous coal from the D bed at Hastings, Cambria County, on the Pennsylvania Railroad, was designated Pennsylvania No. 16. The coal, as worked from the outcrop at this place, averages 4 feet 4 inches in thickness.

One sample, shipped under the supervision of K. M. Way, consisted of run-of-mine coal, and was used in steaming tests 468 (on briquets) and 471, producer-gas test 148, and briqueting tests 172, 173, and *174.*

Two mine samples were taken for chemical analysis. Sample 4028 was taken several hundred feet from the opening, where the coal measured 4 feet 6 inches in thickness. Sample 4029 was taken on the other side of the mine, where the coal measured 4 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 16.

	Mine samples.		Car Sample.	Steaming tests.[a]	
				468.	471.
Laboratory No	4028	4029	4169	4253	.....
Air-drying loss	2.30	2.30	3.90	.....	.....
Proximate:					
Moisture	2.86	2.74	4.25	5.27	4.16
Volatile matter	22.64	22.66	21.79	23.69	21.07
Fixed carbon	67.71	67.37	66.09	62.69	65.84
Ash	6.79	7.23	7.87	8.35	8.93
Sulphur	1.42	1.51	1.59	1.68	1.60
Ultimate:					
Hydrogen	.....	.....	4.72	4.36	4.38
Carbon	.....	.....	75.92	79.42	78.32
Nitrogen	.....	.....	1.28	1.29	1.33
Oxygen	.....	.....	8.62	4.35	4.98
Ash	.....	.....	.....	8.81	9.32
Sulphur	.....	.....	.....	1.77	1.67
Calorific value determined (as received) calories	.....	7,858	7,507	.....	.....
Calorific value determined (as received) B. t. u.	.....	14,144	13,513	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Pennsylvania No. 16 (run of mine).

	Test 468.	Test 471.
Size as used:		
Over 1 inch ... per cent	See p. 206.	7.2
½ inch to 1 inch ... do		11.6
¼ inch to ½ inch ... do		18.8
Under ¼ inch ... do		62.4
Average diameter ... inch		.39
Duration of test ... hours	8.10	10.03
Heating value of fuel ... B. t. u. per pound dry fuel	14,238	13,939
Force of draft:		
Under stack damper ... inch water	0.73	0.76
Above fire ... do	.14	.20
Furnace temperature ... °F	2,855	2,785
Dry fuel used per square foot of grate surface per hour ... pounds	19.04	18.52
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.77	3.53
Percentage of rated horsepower of boiler developed	105.7	98.90
Water apparently evaporated per pound of fuel as fired ... pounds	7.78	7.59
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ... do	9.40	9.15
Per pound of dry fuel ... do	9.92	9.55
Per pound of combustible ... do	11.03	11.03
Efficiency of boiler, including grate ... per cent	67.28	66.16
Fuel as fired:		
Per indicated horsepower hour ... pounds	3.01	3.09
Per electrical horsepower hour ... do	3.71	3.82
Dry fuel:		
Per indicated horsepower hour ... do	2.85	2.96
Per electrical horsepower hour ... do	3.52	3.66

Remarks.—Test 468 on briquets, equal weights, from tests 172, 173, and 174. Briquets from both machines burned slowly with very hot fire, medium length flame, and no smoke; 41 per cent heavy, rough, brittle clinker of gray color; small amount of fine unburnt coal contained in ash.

PRODUCER-GAS TEST.

Pennsylvania No. 16 (run of mine).

Test 148.—Duration of test, 50 hours. Average electrical horsepower, 199.2. Average B. t. u. per cubic foot of gas, 149.5. Total coal fired, 9,950 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.04	0.99	0.90
Developed at switchboard	1.00	.95	.87
Per brake horsepower:			
Commercially available	.89	.84	.77
Developed at engine	.85	.80	.74
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.17	1.11	1.01
Developed at switchboard	1.12	1.06	.97
Per brake horsepower:			
Commercially available	.99	.94	.86
Developed at engine	.95	.90	.82

Analyses.

Coal.		*Gas by volume.*	
Moisture	5.32	Carbon dioxide (CO_2)	10.1
Volatile matter	21.75	Carbon monoxide (CO)	18.2
Fixed carbon	64.94	Hydrogen (H_2)	15.8
Ash	7.99	Methane (CH_4)	2.3
Sulphur	1.60	Nitrogen (N_2)	53.2
		Ethylene (C_2H_4)	.4

BRIQUETTING TESTS.

Pennsylvania No. 16 (run of mine).

Tests 172, 173, 174.—Size as used: Over ¼ inch, 2.2 per cent; $\frac{1}{16}$ inch to ¼ inch, 5.4 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 11.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 21.4 per cent; through $\frac{1}{40}$ inch, 59.8 per cent. There was no difference in physical appearance between English briquets with 6 and those with 7 per cent binder. All briquets were satisfactory, with smooth, very hard surface, characteristic glossy fracture, and sharp edges. Renfrow briquets broke without crumbling and were easily handled from machine when warm. For analyses of briquets see page 205 (steaming test 468).

	Test 172.	Test 173.	Test 174.
Details of manufacture:			
Machine used	Eng.	Eng.	Renf.
Temperature of briquets ... °F.	203	203	185
Binder—			
Kind	c. t. p.	c. t. p.	c. t. p.
Laboratory No. (see p. 40)	4319	4319	4319
Amount ... per cent	6	7	7
Weight of—			
Fuel briquetted ... pounds	3,500	3,500	5,000
Briquets, average ... do	3.66	3.69	0.428
Heat value per pound			
Fuel as received ... B. t. u.	13,513	13,513	13,513
Fuel as fired ... do	13,487	13,487	13,487
Binder ... do	16,139	16,139	16,139
Drop test (1-inch screen):			
Held ... per cent	76.1	80.4	44.5
Passed ... do	23.9	19.6	55.5
Tumbler test (1-inch screen):			
Held ... do	78.8	81.7	69.5
Passed (fines) ... do	21.2	18.3	30.5
Fines through 10-mesh sieve ... do	64.0	63.9	91.0
Weathering test:			
Time exposed ... days	54	50	54
Condition	A.	A.	B.
Water absorption:			
In 19 days ... per cent	13.9	14.7	19.0
Average for first 4 days ... do	1.35	1.30	3.30
Specific gravity (apparent)	1.113	1.110	1.056

Extraction analyses.

		Pitch.	Fuel.	Briquets, tests 172, 173, 174.
Laboratory No		4319	4169	4253
Air-drying loss	per cent		3.90	4.50
Extracted by CS_2:				
Air-dried	do		.06	5.60
As received	do	66.25	.06	5.35
Pitch in briquets, as received	do			8.00

PENNSYLVANIA NO. 17.

Bituminous coal from the Upper Freeport or E bed at White, Indiana County, on the Pennsylvania Railroad, was designated Pennsylvania No. 17. The coal, as worked from the outcrop at this place, averages 3 feet 3 inches in thickness.

One sample, shipped under the supervision of A. K. Adams, consisted of run-of-mine coal, and was used in steaming tests 496 and 506, producer-gas test 158, washing test 189, and coking tests 178 (raw) and 186 (washed).

Two mine samples were taken for chemical analysis. Sample 4336 was taken 700 feet southwest of the opening, where the coal measured 3 feet 3½ inches in thickness. Sample 4337 was taken 485 feet west of the opening, where the coal measured 3 feet 3 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 17.

	Mine samples.		Car sample.	Steaming tests.[a]	
				496.	506.
Laboratory No	4336	4337	4421		
Air-drying loss	1.30	1.30	3.30		
Proximate:					
Moisture	2.22	2.22	4.35	3.45	2.81
Volatile matter	30.91	30.95	27.76	28.33	27.91
Fixed carbon	59.67	58.41	55.99	55.62	57.85
Ash	7.20	8.42	11.90	12.60	11.43
Sulphur	1.39	1.54	1.51	1.55	1.66
Ultimate:					
Hydrogen			5.04	4.73	4.79
Carbon			71.62	74.32	75.36
Nitrogen			1.39	1.44	1.46
Oxygen			8.54	4.85	4.92
Ash				13.05	11.76
Sulphur				1.61	1.71
Calorific value determined (as received) calories		7,767	7,202		
Calorific value determined (as received) B. t. u.		13,801	12,964		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Pennsylvania No. 17 (run of mine).

		Test 496.	Test 506.
Size as used:			
Over 1 inch	per cent	14.4	6.3
½ inch to 1 inch	do	28.1	15.8
¼ inch to ½ inch	do	22.3	22.1
Under ¼ inch	do	35.2	55.8
Average diameter	inch	0.62	0.43
Duration of test	hours	10.00	9.23
Heating value of coal	B. t. u. per pound of dry coal	13,455	13,644
Force of draft:			
Under stack damper	inch water	0.86	0.76
Above fire	do	.21	.06
In ash pit	do	.....	.32
Furnace temperature	°F.	2,768	2,444
Dry coal used per square foot of grate surface per hour	pounds	20.00	20.00
Equivalent water evaporated per square foot of water-heating surface per hour, pounds		3.63	3.50
Percentage of rated horsepower of boiler developed		101.8	98.00
Water apparently evaporated per pound of coal as fired	pounds	7.28	7.02
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	8.78	8.51
Per pound of dry coal	do	9.09	8.76
Per pound of combustible	do	10.76	10.16
Efficiency of boiler, including grate	per cent	65.24	62.00
Coal as fired:			
Per indicated horsepower hour	pounds	3.22	3.32
Per electrical horsepower hour	do	3.98	4.10
Dry coal:			
Per indicated horsepower hour	do	3.11	3.23
Per electrical horsepower hour	do	3.84	3.99

PRODUCER-GAS TEST.

Pennsylvania No. 17 (run of mine).

Test 158.—Duration of test, 50 hours. Average electrical horsepower, 188.4. Average B. t. u. per cubic foot of gas, 141.2. Total coal fired, 13,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.46	1.39	1.21
Developed at switchboard	1.40	1.34	1.16
Per brake horsepower:			
Commercially available	1.24	1.19	1.03
Developed at engine	1.19	1.14	0.99
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.55	1.48	1.28
Developed at switchboard	1.49	1.42	1.23
Per brake horsepower:			
Commercially available	1.31	1.26	1.09
Developed at engine	1.26	1.21	1.05

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.40	Carbon dioxide (CO_2)	10.0
Volatile matter	28.01	Carbon monoxide (CO)	17.5
Fixed carbon	54.87	Hydrogen (H_2)	13.7
Ash	12.72	Methane (CH_4)	2.2
Sulphur	1.75	Nitrogen (N_2)	56.1
		Oxygen (O_2)	.1
		Ethylene (C_2H_4)	.4

WASHING TESTS.

Pennsylvania No. 17.

Test 189.—Duration of test, 1½ hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 r. p. m.; stroke, 2½ inches. Raw coal, 7.28 tons; washed coal, 6.30 tons, 87 per cent; refuse, 0.98 ton, 13 per cent.

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4421	4.35	11.90	.....	1.51	.....
Washed coal, test 189	4598	5.18	8.02	33	1.16	23
Refuse	.....	4.58	41.50	.....	8.85	.....

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analyses.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent. reduction.	Per cent.	Per cent. reduction.
On raw coal (preliminary):									
1	¾	1.35	.....	86	14	5.14	57	1.00	34
2	¾	1.40	.....	90	10	5.69	52	1.08	28
3	¾	1.45	.....	91	9	6.20	48	1.26	17
4	¾	1.52	.....	91	9	7.51	37	1.13	25
On refuse (float): [a]									
1	.....	1.35	13.00	1.70	.....	5.39	.....	1.28	.....
2	.....	1.41	14.00	1.80	.....	6.20	.....	1.40	.....
3	.....	1.45	19.30	2.60	.....	8.15	.....	1.47	.....
4	.....	1.51	23.75	3.20	.....	9.51	.....	1.67	.....

[a] Loss of good coal as calculated, 1.5 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal.

COKING TESTS.

Pennsylvania No. 17 (run of mine).

		Test 178 (raw).	Test 186 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	52	44
Coal charged	pounds	12,220	11,920
Coke produced	do	7,923	7,523
	per cent	64.94	63.11
Breeze produced	pounds	356	307
	per cent	2.92	2.58
Total yield	do	67.86	65.69

Remarks.—Test 178: Light-gray and silvery; good weight coke; ash high. Test 186: Good, strong, heavy coke; light-gray and silvery. Washing improves both physical appearance and chemical analysis, reducing ash and sulphur.

Analyses.

	Test 178.		Test 186.	
	Coal.	Coke.	Coal.	Coke.
Moisture	4.41	0.22	6.30	0.29
Volatile matter	28.83	.36	28.24	.56
Fixed carbon	57.86	84.55	57.22	87.96
Ash	8.90	14.87	8.24	11.19
Sulphur	1.39	1.37	1.19	1.00

PENNSYLVANIA NO. 18.

Bituminous coal from a mine working the "Miller" bed, outcropping at Lloydell, Cambria County, on the Pennsylvania Railroad, was designated Pennsylvania No. 18.

This sample consisted of run-of-mine coal shipped under the supervision of K. M. Way, and was used in steaming tests 499 and 515 (on briquets); briquetting tests 196*, 197*, 200*, 201, 202, 205, 232*†, 236†, and 250†; mixed with Rhode Island No. 1 in briquetting test 243†; and mixed with Miscellaneous No. 9 in briquetting tests 238†, 239†, 240†, and 248. Four cars were shipped to the plant, and one car was shipped to the Pennsylvania Railroad locomotive-testing plant at Altoona.

Two mine samples were taken for chemical analysis. Sample 4347 was cut from the left entry, 2,500 feet south of the mouth of the drift. Sample 4348 was taken from the face of the fifth left entry, 3,200 feet south of the mouth of the drift.

Six car samples were taken—sample 4509 for complete chemical analysis, and five others for air-drying loss and moisture, as follows:

Laboratory No.	4490	4514	4547	4505	4499
Air-drying loss	8.10	3.80	4.40	6.20	4.60
Moisture	8.72	4.32	5.01	6.60	5.14

CHEMICAL ANALYSES.

Pennsylvania No. 18.

	Mine samples.		Car sample.	Steaming tests.[a]	
				499.	515.
Laboratory No.	4347	4348	4509	1512	4755
Air-drying loss	1.90	2.20	4.10	.....	.....
Proximate:					
Moisture	2.43	2.66	4.46	4.05	5.95
Volatile matter	17.75	17.60	15.44	19.68	18.41
Fixed carbon	73.21	71.18	71.63	66.56	67.00
Ash	6.61	8.56	8.47	9.71	8.64
Sulphur	1.34	2.97	1.49	1.72	1.34
Ultimate:					
Hydrogen	.....	.....	4.80	4.29	4.16
Carbon	.....	.....	77.43	79.76	80.41
Nitrogen	.....	.....	11.28	1.05	1.19
Oxygen	.....	.....	6.53	2.99	3.63
Ash	.....	.....	.....	10.12	9.19
Sulphur	.....	.....	.....	1.79	1.42
Calorific value determined (as received) calories	.....	7,775	7,601	.....	.....
Calorific value determined (as received) B. t. u.	.....	13,995	13,682	.....	.....

	Briquetting tests.[b]								
	196*.	200*.	232*†,205.	236†.	238†.	239†.	240†.	243†.	250†.
Proximate:									
Moisture	3.25	3.01	2.41	4.71	1.83	1.30	1.06	1.34	2.55
Volatile matter	18.17	17.84	19.41	18.43	15.05	13.73	15.87	16.39	24.23
Fixed carbon	69.87	70.53	68.86	69.14	69.52	69.67	69.24	70.34	62.80
Ash	8.71	8.62	9.32	7.72	13.60	13.50	13.83	11.93	10.42
Sulphur	1.42	1.38	1.75	1.19	1.61	1.19	1.44	1.37	1.99
Ultimate:									
Hydrogen	4.12	4.13	4.10	4.40	3.12	2.81	2.81	3.46	4.36
Carbon	81.41	82.27	81.20	81.77	77.24	70.94	76.02	77.79	78.64
Nitrogen	1.19	1.27	1.11	1.26	.70	.75	.81	.53	.88
Oxygen	2.81	2.02	2.25	3.22	3.48	8.79	4.92	4.74	3.39
Ash	9.00	8.89	9.55	8.10	13.82	15.50	13.98	12.09	10.69
Sulphur	1.47	1.42	1.79	1.25	1.64	1.21	1.46	1.39	2.04

[a] *Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.*
[b] *Proximate analysis of fuel as received; ultimate analysis on dry basis.*

STEAMING TESTS.

Pennsylvania No. 18 (briquets).

	Test 499.	Test 515.
Duration of test.....hours..	8.58	9.22
Heating value of fuel.....B. t. u. per pound dry fuel..	14,119	14,292
Force of draft:		
Under stack damper.....inch water..	0.81	0.84
Above fire.....do....	.19	.18
Furnace temperature.....°F..	2,854	2,709
Dry fuel used per square foot of grate surface per hour.....pounds..	21.50	21.13
Equivalent water evaporated per square foot of water-heating surface per hour.....pounds..	4.09	4.02
Percentage of rated horsepower of boiler developed.....	114.7	112.6
Water apparently evaporated per pound of fuel as fired.....pounds..	7.54	7.38
Water evaporated from and at 212 °F.:		
Per pound of fuel as fired.....do....	9.14	8.95
Per pound of dry fuel.....do....	9.52	9.52
Per pound of combustible.....do....	10.72	10.62
Efficiency of boiler, including grate.....per cent..	65.11	64.33
Fuel as fired:		
Per indicated horsepower hour.....pounds..	3.09	3.16
Per electrical horsepower hour.....do....	3.82	3.90
Dry fuel:		
Per indicated horsepower hour.....do....	2.97	2.97
Per electrical horsepower hour.....do....	3.66	3.67

Remarks.—Test 499 on Renfrow briquets from tests 201 and 202; test 515 on English briquets from test 197*. English briquets fired whole, both burned with short flame, intense white heat, and no smoke. English briquets made 26 per cent clinker; Renfrow briquets made 44 per cent clinker.

BRIQUETTING TESTS.

Pennsylvania No. 18 (run of mine).

Tests 196, 197*, 200*, 201, 202, 205, 232*, 236†, and 250†.*—Size as used: Over ¼ inch, 1.4 per cent; $\frac{1}{10}$ inch to ¼ inch, 5 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 10.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 24.8 per cent; through $\frac{1}{40}$ inch, 58.2 per cent. Excellent briquets were made with 5, 6, and 7 per cent binder on the English machine; 8 per cent binder gave good results on the Renfrow machine, but those with 6 and 7 per cent binder were not satisfactory. This coal worked equally well with high and low moisture content, making briquets with hard surfaces that were easily handled and piled. The fracture was smooth, the particles of coal being so thoroughly cemented that the appearance was like a solid mass. For analyses of briquets see page 210 (briquets from tests 201 and 202 under "Steaming test 499," from test 197* under "Steaming test 515").

	Test 196*.	Test 197*.	Test 200*.	Test 201.	Test 202.	Test 205.	Test 232*†.	Test 236†.	Test 250†.
Details of manufacture:									
Machine used.....	Eng.	Eng.	Eng.	Renf.	Renf.	Renf.	Renf.	Eng.	English
Temperature of briquets.....°F..	158	140	185	149	149	158	167	158	157
Binder—									
Kind.....	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	(a)
Laboratory No. (see p. 40).	4683	4683	4683	4683	4683	4806	4806	4806	4825
Amount, per cent..	6	7	5	6	7	8	8	7	8
Weight of—									
Fuel briquetted, pounds.....	24,000	128,000	24,000	3,600	6,500	6,000	146,000	40,000	1,800
Briquets, average, pounds.....	3.57	3.62	3.66	0.456	0.439	0.407	0.469	3.62	3.91
Heat value per pound—									
Fuel as received, B. t. u.....	13,682	13,682	13,682	13,682	13,682	13,682	13,682	13,682	13,682
Fuel as fired, B. t. u.....	14,029	13,442	13,946	13,547	13,547	13,937	13,937	13,873	13,680
Binder....B. t. u..	16,637	16,637	16,637	16,637	16,637	16,637	16,864	16,864	17,156

[a] Wax tailings.

BRIQUETTING TESTS—Continued.

Pennsylvania No. 18 (run of mine).

	Test 196*.	Test 197*.	Test 200*.	Test 201.	Test 202.	Test 205.	Test 232*†.	Test 236†.	Test 250†.
Drop test (1-inch screen):									
Held.....per cent..	70.6	66.7	62.5	21.0	41.0	54.5	54.5	67.5	89.0
Passed.....do....	29.4	33.3	37.5	79.0	59.0	45.5	45.5	32.5	11.0
Tumbler test (1-in. screen):									
Held.....per cent..	66.0	66.1	72.2	51.0	71.0	85.0	89.5	61.8	91.9
Passed (fines)...do....	34.0	33.9	27.8	49.0	29.0	15.0	10.5	38.2	8.1
Fines through 10-mesh sieve.....per cent..	76.0	59.5	77.6	89.7	89.2	89.7	90.3	53.4	46.2
Weathering test:									
Time exposed...days..	1	.....	.....	.....	.....	.....	.....	.....	.....
Condition.....	A.	.....	.....	.....	.....	.....	.....	.....	.....
Water absorption:									
In 19 days...per cent..	14.9	12.0	.....	.....	.....	.....	.....	.....	.....
In 13 days.....do....	.....	.....	11.5	17.4	16.0	15.3	11.0	11.7	5.9
Average for first 4 days, per cent.....	1.85	1.55	2.10	3.12	2.88	2.33	1.83	2.13	0.95
Specific gravity (apparent).	1.129	1.161	1.131	1.088	1.106	1.102	1.164	1.156	1.240

Extraction analyses.[a]

	Fuel.	Briquets.						
		Test 196*.	Test 197*.	Test 200*.	Tests 201, 202.	Tests 205, 232*†.	Test 236†.	Test 250†.
Laboratory No.....	4490	5061	4755	5052	4512	5049	4797	4906
Air-drying loss.....per cent..	8.10	.....	5.10	.....	3.90	.....	3.80	1.70
Extracted by CS_2:								
Air-dried.....do....	.76	.....	5.91	.....	5.96	.....	7.69	8.10
As received.....do....	.69	5.44	5.61	4.68	5.73	8.11	7.38	7.96
Pitch in briquets as received..do....	.....	5.36	5.56	4.51	5.70	7.78	6.98	7.33

[a] For extraction analyses of pitches used, see p. 40.

Test 238†.—Pennsylvania No. 18, 75 per cent; miscellaneous No. 9 (coke breeze), 25 per cent. Satisfactory briquets were made with 8 per cent binder; similar to briquets from Pennsylvania No. 18, alone. Surfaces smooth and hard; fractured surface smooth with sharp edges; could be handled easily while warm, and did not crush or stick together when piled warm.

Test 239†.—Equal parts of Pennsylvania No. 18 and miscellaneous No. 9. The briquets were softer when warm than in test 238†, but could be handled without breaking; very hard when cold; broke without crumbling; fractured surface rough but firm.

Test 240†.—Pennsylvania No. 18, 25 per cent; miscellaneous No. 9, 75 per cent. The briquets were very soft when warm and could not be handled without considerable breakage, but hard when cold; fractured surface very rough, with edges that crumbled easily. This test showed the necessity of handling fuel mechanically until cold to prevent breakage.

Test 243†.—Equal parts of Pennsylvania No. 18 and Rhode Island No. 1, both run of mine. An effort was made to improve the burning qualities by increasing the melting point of the binder, but owing to the hardness of the pitch used and insufficient pressure, these briquets were not satisfactory. They could not be handled when warm without many being broken, but when cold were brittle, producing considerable slack in handling. No physical tests were made.

Test 248.—Pennsylvania No. 18, 10 per cent; miscellaneous No. 9, 90 per cent. Characteristics of briquets noted in test 240† were more pronounced. The breakage of warm briquets in falling from machine and during handling with coke fork was

fully 50 per cent, showing the necessity of careful handling of briquets on a belt conveyor until they are cool. The cold briquets were handled satisfactorily.

For analyses of briquets, see page 210.

	Test 238†.	Test 239†.	Test 240†.	Test 243†.	Test 248.
Size as used:					
Over ½ inch ... per cent	1.0	0.6	1.4	1.0	1.4
5/16 inch to ½ inch ... do	6.8	6.2	7.8	6.8	8.4
3/16 inch to 5/16 inch ... do	14.2	15.0	16.6	17.6	16.8
1/16 inch to 3/16 inch ... do	21.8	23.4	26.2	25.2	29.0
Under 1/16 inch ... do	56.2	54.8	48.0	49.4	44.4
Details of manufacture:					
Machine used	Renf.	Renf.	Renf.	Renf.	Renf.
Temperature of briquets ... °F	167	167	167	185	158
Binder—					
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4906	4906	4906	4625	4879
Amount ... per cent	8.0	8.0	8.0	8.0	8.0
Weight of—					
Fuel briquetted ... pounds	10,000	8,000	8,000	2,000	2,000
Briquets, average ... do	0.485	0.479	0.568	.....	0.479
Heat value per pound—					
Fuel as received: Pa. No. 18 ... B. t. u.	13,682	13,682	13,682	13,682	13,682
Fuel as received: R. I. No. 1 ... do	.....	.....	.....	10,996	.....
Fuel as received: Misc. No. 9 ... do	10,870	10,870	10,870	.....	10,870
Fuel as fired ... do	13,185	12,787	12,721	13,387	.....
Binder	16,864	16,864	16,864	16,576	16,805
Drop test (1-inch screen):					
Held ... per cent	48.0	56.5	40.0	.....	61.0
Passed ... do	52.0	43.5	60.0	.....	39.0
Tumbler test (1-inch screen):					
Held ... do	87.0	78.5	90.0	.....	80.0
Passed (fines) ... do	13.0	21.5	10.0	.....	20.0
Fines through 10-mesh sieve ... do	84.4	92.6	100.0	.....	85.2
Water absorption:					
In 23 days ... do	.....	.....	.....	.....	19.5
In 10 days ... do	.....	15.8	.....	.....	.....
In 9 days ... do	.....	.....	14.0	.....	.....
In 8 days ... do	13.9	.....	.....	.....	.....
Average for first—					
7 days ... do	.....	2.07	.....	.....	.....
5 days ... do	2.42	.....	2.4	.....	2.68
4 days ... do	.....	.....	.....	.....	.....
Specific gravity (apparent)	1.165	1.177	1.280	.....	1.148

Extraction analyses.

	Pitches.		Fuels.			Briquets.			
			Pa. No. 18.	R. I. No. 1.	Misc. No. 9.	Test 238†.	Test 239†.	Test 240†.	Test 243†.
Laboratory No.	4625	4806	4490	3141	4763	4930	4932	4977	4832
Air-drying loss ... per cent	.....	.....	8.10	3.40	1.30	1.00	0.90	.....	0.70
Extracted by CS_2:									
Air-dried ... do	.....	.....	.76	.02	.15	7.21	7.55	.....	8.91
As received ... do	90.56	96.90	.69	.02	.15	7.21	7.52	7.43	8.84
Pitch in briquets as received ... per cent	.....	.....	.....	.....	.....	7.17	7.35	7.14	9.41

PENNSYLVANIA NO. 19.

Bituminous coal from the Pittsburg bed one-fourth mile north of Herminie, Westmoreland County, on the Pennsylvania Railroad, was designated Pennsylvania No. 19. The coal, as worked at a depth of 300 feet at this place, averages 6 feet 2¼ inches in thickness.

One sample, consisting of run-of-mine coal shipped under the supervision of A. K. Adams, was used in steaming tests 498 and 508 (on briquets), coking tests 176 and 177, and briquetting tests 218, 219, and 242.

Two mine samples were taken for chemical analysis. Sample 4351 was taken 1,400 feet north of the opening, where the coal measured 5 feet 8¾ inches in thickness. Sample 4352 was taken 4,000 feet south of the opening, where the coal measured 6 feet 7¾ inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 19.

	Mine samples.		Car sample.	Steaming tests.[a]		Briquetting test 242.[a]
				498.	508.	
Laboratory No.	4351	4352	4489	.....	4648	4828
Air-drying loss	1.70	1.00	2.40	.....	.....	0.50
Proximate:						
Moisture	2.81	2.01	3.39	3.20	5.12	1.75
Volatile matter	32.21	33.56	31.79	31.65	33.00	33.50
Fixed carbon	58.71	58.11	56.46	57.32	54.36	55.24
Ash	6.27	6.32	8.36	7.83	7.52	9.51
Sulphur	.99	1.39	1.05	1.51	1.05	1.36
Ultimate:						
Hydrogen	.....	.....	5.07	4.86	4.76	4.52
Carbon	.....	.....	74.42	77.11	77.93	75.91
Nitrogen	.....	.....	1.39	1.44	1.41	1.35
Oxygen	.....	.....	9.71	6.94	6.86	7.16
Ash	.....	.....	.....	8.09	7.93	9.69
Sulphur	.....	.....	.....	1.56	1.11	1.38
Calorific value determined (as received) calories	.....	7,862	7,566	.....	.....	7,581
Calorific value determined (as received) B. t. u.	.....	14,152	13,699	.....	.....	13,646

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Pennsylvania No. 19 (run of mine).

	Test 498.	Test 508.
Size as used:		
Over 1 inch ... per cent	67.1	See p. 215.
½-inch to 1 inch ... do	12.4	
¼-inch to ½-inch ... do	7.8	
Under ¼-inch ... do	12.7	
Average diameter ... inches	1.99	
Duration of test ... hours	9.50	9.38
Heating value of fuel ... B. t. u. per pound of dry fuel	14,128	14,270
Force of draft:		
Under stack damper ... inch water	0.86	0.97
Above fire ... do	.19	.23
Furnace temperature ... °F	2,828	.....
Dry fuel used per square foot of grate surface per hour ... pounds	20.42	20.96
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.81	4.05
Percentage of rated horsepower of boiler developed	106.8	113.7
Water apparently evaporated per pound of fuel as fired ... pounds	7.48	7.58
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ... do	9.05	9.20
Per pound of dry fuel ... do	9.35	9.69
Per pound of combustible ... do	10.48	10.79
Efficiency of boiler, including grate ... per cent	63.91	65.58
Fuel as fired:		
Per indicated horsepower hour ... pounds	3.12	3.07
Per electrical horsepower hour ... do	3.86	3.79
Dry fuel:		
Per indicated horsepower hour ... do	3.02	2.92
Per electrical horsepower hour ... do	3.73	3.60

Remarks.—Test 508 on briquets, equal parts from tests 218 and 219.

COKING TESTS.

Pennsylvania No. 19 (run of mine).

		Test 176.	Test 177.
Size as used		r. o. m.	f. c.
Duration of test	hours	36	40
Coal charged	pounds	12,110	12,100
Coke produced	do	7,800	8,490
	per cent	64.41	70.17
Breeze produced	pounds	315	336
	per cent	2.60	2.78
Total yield	do	67.01	72.95

Remarks.—Test 176: Good heavy coke; light gray with a little silvery deposit of carbon. Brittleness probably due to unbroken pieces of slate. Test 177: Good heavy coke; light gray and silvery. Crushing improves physical properties of coke and increases yield. Breakage, good large uniform-sized pieces.

Analyses.

	Test 176.		Test 177.	
	Coal.	Coke.	Coal.	Coke.
Moisture	3.01	0.24	3.57	0.13
Volatile matter	30.66	.19	29.56	.49
Fixed carbon	57.17	88.06	59.17	87.45
Ash	9.16	11.51	7.70	11.93
Sulphur	1.16	.95	.98	.83

BRIQUETTING TESTS.

Pennsylvania No. 19 (run of mine).

Tests 218, 219, 242.—Size as used: Over ¼-inch, 3 per cent; $\frac{1}{16}$-inch to ¼-inch, 8.8 per cent; $\frac{1}{20}$-inch to $\frac{1}{16}$-inch, 17 per cent; $\frac{1}{40}$-inch to $\frac{1}{20}$-inch, 26.3 per cent; through $\frac{1}{40}$-inch, 47.6 per cent.

Briquets with 6, 7, and 8 per cent binder appeared equally satisfactory. Edges were sharp, surfaces hard and smooth, fracture clear with firm edges. Renfrow briquets had a glossy surface. All briquets handled and piled well. For analyses of briquets see page 214 (those from tests 218 and 219 under "Steaming test 508").

		Test 218.	Test 219.	Test 242.
Details of manufacture:				
Machine used		Eng.	Eng.	Renf.
Temperature of briquets	°F.	185	185	149
Binder—				
Kind		w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)		4683	4683	4806
Amount	per cent	6	7	8
Weight of—				
Fuel briquetted	pounds	8,000	4,000	4,000
Briquets, average	do	3.65	3.74	0.431
Heat value per pound—				
Fuel as received	B. t. u.	13,699	13,699	13,699
Fuel as fired	do	13,540	13,540	13,646
Binder	do	16,637	16,637	16,864
Drop test (1-inch screen):				
Held	per cent	73.8	78.5	78.5
Passed	do	26.2	21.5	21.5
Tumbler test (1-inch screen):				
Held	do	75.6	78.8	91.5
Passed (fines)	do	24.4	21.2	8.5
Fines through 10-mesh sieve	do	70.0	65.0	90.09
Water absorption:				
In 13 days	do	8.6	8.4	.....
In 10 days	do	.....	.....	7.9
Average or first 8 days	do	1.0	1.0	1.0
Specific gravity (apparent)		1.124	1.133	1.125

Extraction analyses.

	Pitches.		Fuel.	Briquets.	
				Tests 218, 219.	Test 242.
Laboratory No	4683	4806	4681	4648	4828
Air-drying loss ... per cent	.....	.....	1.00	4.00	0.50
Extracted by CS_2:					
Air-dried ... do	.....	.....	.75	6.04	9.75
As received ... do	89.31	96.90	.74	5.80	9.16
Pitch in briquets, as received ... do	.....	.....	.....	5.71	8.21

PENNSYLVANIA NO. 20.

Bituminous coal from the Lower Kittanning or B bed, 1½ miles east of Seward, Westmoreland County, on the Pennsylvania Railroad, was designated Pennsylvania No. 20. This coal, as worked from the outcrop at this place, averages 3 feet 7 inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal, and was used in steaming tests (on briquets) 512 and 514; washing test 194; coking tests 179 and 182; and briquetting tests 198†, 208, 209, 212, 213†, 215, and 216.

Two mine samples were taken for chemical analysis. Sample 4349 was taken 1,850 feet south of the opening, where the coal measured 3 feet 9 inches in thickness. Sample 4350 was taken 1,050 feet southwest of the opening, where the coal measured 3 feet 5 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 20.

	Mine samples.		Car sample.	Steaming tests.[a]		Briquetting tests.[b]	
				512.	514.	198†.	213†.
Laboratory No	4349	4350	4517	4726	4713	4769	4885
Air-drying loss	2.30	2.00	.....	.....	.....	.....	.....
Proximate:							
Moisture	2.80	2.48	4.00	3.50	2.79	6.16	1.23
Volatile matter	17.92	17.87	15.89	19.98	21.11	19.23	20.58
Fixed carbon	71.32	70.41	69.57	67.71	67.79	64.38	67.74
Ash	7.96	9.24	10.54	8.81	8.31	10.23	10.45
Sulphur	2.29	3.03	2.85	1.59	1.91	2.68	2.98
Ultimate:							
Hydrogen	.....	.....	.....	4.39	4.42	4.20	4.56
Carbon	.....	.....	.....	81.06	80.25	78.12	79.21
Nitrogen	.....	.....	.....	1.06	1.09	1.09	1.12
Oxygen	.....	.....	.....	2.72	3.73	2.83	1.51
Ash	.....	.....	.....	9.13	8.55	10.90	10.58
Sulphur	.....	.....	.....	1.64	1.96	2.86	3.02
Calorific value determined (as received) calories	.....	7,679	7,415	.....	.....	.....	.....
Calorific value determined (as received) B. t. u.	.....	13,822	13,347	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Pennsylvania No. 20 (briquets).

	Test 512 (w.).	Test 514.
Duration of test ..... hours..	7.77	7.93
Heating value of fuel ..... B. t. u. per pound of dry fuel..	14,495	14,382
Force of draft:		
Under stack damper ..... inch water..	0.93	0.93
Above fire ..... do....	.19	.23
Dry fuel used per square foot of grate surface per hour ..... pounds..	19.93	27.52
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.84	4.47
Percentage of rated horsepower of boiler developed	107.7	125.3
Water apparently evaporated per pound of fuel as fired ..... pounds..	7.70	6.54
Water evaporated from and at 212 °F.:		
Per pound of fuel as fired ..... do....	9.32	7.91
Per pound of dry fuel ..... do....	9.65	8.14
Per pound of combustible ..... do....	10.76	9.06
Efficiency of boiler, including grate ..... per cent..	64.29	54.66
Fuel as fired:		
Per indicated horsepower hour ..... pounds..	3.03	3.58
Per electrical horsepower hour ..... do....	3.75	4.41
Dry fuel:		
Per indicated horsepower hour ..... do....	2.93	3.47
Per electrical horsepower hour ..... do....	3.62	4.29

Remarks.—Test 512 on briquets from tests 215 and 216 (equal weights); briquets burned freely, with intense heat and no smoke; 31 per cent clinker. Test 514 on briquets from tests 208 and 209 (equal weights); briquets burned freely, with intense heat and no smoke; 50 per cent clinker.

WASHING TESTS.

Pennsylvania No. 20.

Test 194.—Duration of test, 2¾ hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 r. p. m.; stroke, 2½ inches. Raw coal, 22.21 tons; washed coal, 17.25 tons, 78 per cent; refuse, 4.96 tons, 22 per cent.

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur.	
			Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4517	4.00	10.54	.....	2.85	.....
Washed coal, test 194	4553	6.48	6.76	36	1.30	54
Refuse	.....	10.21	46.25	.....	17.40	.....

Float and sink tests.

Number of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analyses.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	¾	1.35	.....	83	17	4.95	53	0.93	67
2	¾	1.42	.....	88	12	5.66	46	1.24	57
3	¾	1.45	.....	88	12	4.72	55	1.02	64
4	¾	1.52	.....	89	11	6.07	42	1.09	62
On refuse (float): [a]									
1	.....	1.35	17.20	3.91	.....	5.42	.....	1.69	.....
2	.....	1.41	18.50	4.20	.....	5.69	.....	1.69	.....
3	.....	1.45	19.88	4.51	.....	6.45	.....	2.15	.....
4	.....	1.53	20.20	4.59	.....	7.89	.....	2.08	.....

[a] Figures indicate that finer crushing is advantageous. Loss of "good coal" in the refuse will not exceed 2 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal.

COKING TESTS.

Pennsylvania No. 20 (run of mine).

		Test 179 (raw).	Test 182 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	68	78
Coal charged	pounds	13,070	11,760
Coke produced	do	8,129	7,350
	per cent	62.20	62.50
Breeze produced	pounds	420	529
	per cent	3.21	4.50
Total yield	do	65.41	67.00

Remarks.—Test 179: Light-gray and silvery color; soft, dense coke; high ash and sulphur. Test 182: Gray color; soft, dense coke; ash and sulphur reduced by washing; no improvement in physical appearance.

Analyses.

	Test 179.		Test 182.	
	Coal.	Coke.	Coal.	Coke.
Moisture	3.91	0.30	6.30	0.51
Volatile matter	16.35	.28	17.04	.58
Fixed carbon	68.30	84.95	69.58	89.85
Ash	11.44	14.47	7.08	9.06
Sulphur	2.78	2.31	1.34	1.11

BRIQUETTING TESTS.

Pennsylvania No. 20 (run of mine).

Tests 198, 208, and 209.—Size as used: Over $\frac{1}{4}$ inch, 0.8 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 3.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 11.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 27.0 per cent; through $\frac{1}{40}$ inch, 57.4 per cent. Briquets from both machines had similar appearance, with smooth, hard surface; were very brittle, and broke with a glossy fracture and sharp edges. The percentage of binder seemed to have little effect on brittleness, although Renfrow briquets, with 8 per cent binder, handled with less breakage.

Tests 212, 213†, 215, and 216 (on washed coal).—Size as used: Over $\frac{1}{4}$ inch, 0.8 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 4.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 16.0 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 26.0 per cent; through $\frac{1}{40}$ inch, 52.4 per cent. There was no noticeable difference between these briquets and those made from raw coal.

For analyses of briquets see page 216 (those from tests 208 and 209 under "Steaming test 514;" from tests 212, 215, and 216 under "Steaming test 512").

	Test 198†.	Test 208.	Test 209.	Test 212.	Test 213†.	Test 215.	Test 216.
Details of manufacture:							
Machine used	Eng.	Renf.	Renf.	Renf.	Renf.	Eng.	Eng.
Temperature of briquets	158	158	158	158	158	176	176
Binder—							
Kind	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4683	4683	4683	4683	4683	4683	4683
Amount per cent	6	7	8	7	8	6	7
Weight of—							
Fuel briquetted pounds	3,200	4,500	8,000	6,500	6,500	6,400	3,300
Briquets, average do	3.52	0.451	0.457	0.427	0.458	3.63	3.44
Heat value per pound—							
Fuel as received B. t. u.	13,347	13,347	13,347	14,639	14,639	14,639	14,639
Fuel as fired do	13,198	13,981	13,981	.....	13,896	13,988	13,988
Binder do	16,637	16,637	16,637	16,637	16,637	16,637	16,637
Drop test (1-inch screen):							
Held per cent	74.8	19.5	26.0	23.0	19.5	74.6	71.9
Passed do	25.2	80.5	74.0	77.0	80.5	25.4	28.1

BRIQUETTING TESTS—Continued.

Pennsylvania No. 20 (run of mine).

	Test 198†.	Test 208.	Test 209.	Test 212.	Test 213†.	Test 215.	Test 216.
Tumbler test (1-inch screen):							
Held.....per cent..	71.0	54.0	61.5	67.0	64.0	74.0	70.5
Passed (fines).....do....	29.0	46.0	38.5	33.0	36.0	26.0	29.5
Fines through 10-mesh sieve.....do....	65.4	86.8	86.4	91.6	87.3	63.2	70.4
Water absorption:							
In 13 days.....do....	14.5	15.5	15.0	19.0	14.5	9.5	11.0
Average for first 5 days.....do....	2.34	2.78	2.66	3.1	2.50	1.56	1.56
Specific gravity (apparent).....	1.141	1.11	1.127	1.043	1.144	1.148	1.121

Extraction analyses.

	Pitch.	Fuel.	Briquets.			
			Test 198†.	Tests 208, 209.	Test 213†.	Tests 215, 216.
Laboratory No.....	4683	4498	4769	4713	4885	4726
Air-drying loss.....per cent..	.....	3.10	5.50	2.00	0.60	3.10
Extracted by CS_2:						
Air-dried.....do....	.....	1.02	5.60	6.86	8.03	6.90
As received.....do....	89.31	.99	5.29	6.72	7.98	6.61
Pitch in briquets as received.....do....	.....	.....	5.00	6.49	7.92	6.37

PENNSYLVANIA NO. 21.

Bituminous coal from the Pittsburg bed, 2 miles southwest of Connellsville, Fayette County, on the Pennsylvania Railroad, was designated Pennsylvania No. 21. The coal, as worked at a depth of 315 feet at this place, averages 7 feet 6¼ inches in thickness.

One sample, shipped under the supervision of A. K. Adams, consisted of run-of-mine coal, and was used in coking tests 183, 187, 189, 191, and 192, and cupola test 190.

Two mine samples were taken for chemical analysis. Sample 4411 was taken 6,500 feet northwest of the opening, where the coal measured 7 feet 5½ inches in thickness. Sample 4412 was taken 9,000 feet northwest of the opening, where the coal measured 7 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Pennsylvania No. 21.

	Mine samples.		Car sample.		Mine samples.		Car sample.
Laboratory No.....	4412	4411	4609	Ultimate:			
Air-drying loss.....	1.80	1.40	4.20	Hydrogen.....		.....	4.91
Proximate:				Carbon.....		.....	73.13
Moisture.....	2.82	2.40	5.13	Nitrogen.....		.....	1.50
Volatile matter.....	29.97	29.90	27.87	Oxygen.....		.....	10.89
Fixed carbon.....	59.84	60.48	58.29	Calorific value determined (as received) calories..	7,773	.....	7,525
Ash.....	7.37	7.22	8.71	B. t. u...	13,991	.....	13,365
Sulphur.....	1.22	.97	.86				

COKING TESTS.

Pennsylvania No. 21 (run of mine).

	Test 183.	Test 187.	Test 189.	Test 191.	Test 192.
Size as used	Not crushed.	f. c.	Not crushed.	Through 1-inch screen.	Through ¾-inch screen.
Duration of test ... hours	70	78	51	47	43
Coal charged ... pounds	15,140	14,360	12,450	11,940	11,500
Coke produced ... do	10,200	9,982	8,457	7,963	7,733
Coke produced ... per cent	67.37	69.51	67.93	66.69	67.24
Breeze produced ... pounds	401	326	319	368	339
Breeze produced ... per cent	2.65	2.27	2.56	3.08	2.95
Total yield ... do	70.02	71.78	78.49	69.77	70.19

Remarks.—Light gray and silvery; good heavy coke.

Analyses.

	Test 183.		Test 187.		Test 189.		Test 191.		Test 192.	
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	5.37	0.71	5.53	0.63	4.05	0.82	4.28	0.33	3.58	0.29
Volatile matter	28.33	.12	27.97	.66	29.26	.21	29.92	.15	28.86	.69
Fixed carbon	59.07	88.24	57.81	87.78	58.29	88.22	58.22	88.54	60.13	88.54
Ash	8.23	10.93	8.69	10.93	8.40	10.75	7.58	10.98	7.43	10.48
Sulphur	.89	.82	.86	.62	.93	.81	.95	.87	.91	.76

Cupola test of coke made from Pennsylvania No. 21 coal.

CHARGE.

Cupola test No.	Coke.[a]			Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.		1.	2.	3.	4.	5.	
					Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
190	187	1.90	7	Coke	210	55	55	55	55	430
				Pig iron	630	405	405	405	405	2,250
				Scrap	210	135	135	135	135	750

[a] Sulphur in ash, 0.0115 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
190	11.00 a. m.	7	6	1,793	691	2,484	25	5,962	7.31	10.16	211	90

LADLE RECORD.

Ladle No.	Pounds.	Time (a. m.).	Ladle No.	Pounds.	Time (a. m.).
1	61	11.10	13	52	11.25
2	132	11.13	14	72	11.25½
3	80	11.15	15	30	11.26
4	62	11.17	16	89	11.26½
5	147	11.17½	17	132	11.28
6	55	11.18	18	64	11.28½
7	49	11.20	19	44	11.29
8	136	11.20½	20	28	11.29½
9	73	11.21	21	100	11.38
10	52	11.22	22	23	11.38½
11	125	11.22½	23	87	11.39
12	83	11.23	24	17	11.39

Remarks.—Test 190: Temperature of iron, medium. Blast off 8 minutes.

PENNSYLVANIA NO. 22.

Bituminous coal from the Pittsburg bed at Huff, Westmoreland County, on the Pennsylvania Railroad, was designated Pennsylvania No. 22.

One sample of this coal, which is worked from the outcrop at this place, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in steaming test 510 (on briquets), producer-gas test 159, and briquetting tests 211†, 222, and 223†. No mine samples covering this shipment were taken.

CHEMICAL ANALYSES.

Pennsylvania No. 22.

	Car sample.	Steaming test 510.[a]	Briquetting tests.[b]	
			211†.	223†.
Laboratory No.	4498	4704	4684	4706
Air-drying loss	3.10	.....	.....	.....
Proximate:				
Moisture	3.98	5.15	2.21	3.55
Volatile matter	28.13	29.60	32.11	30.57
Fixed carbon	57.73	55.08	55.12	54.27
Ash	10.16	10.17	10.56	11.61
Sulphur	1.00	1.17	1.13	1.07
Ultimate:				
Hydrogen	4.96	4.46	4.53	3.55
Carbon	73.34	75.40	75.71	75.94
Nitrogen	1.53	1.39	1.39	1.24
Oxygen	9.01	6.80	6.41	6.12
Ash	.....	10.72	10.80	12.04
Sulphur	.....	1.23	1.16	1.11
Calorific value determined (as received) calories	7,395	.....	.....	.....
Calorific value determined (as received) B. t. u.	13,311	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TEST.

Pennsylvania No. 22 (English briquets).

		Test 510.
Duration of test	hours	9.17
Heating value of fuel	B. t. u. per pound dry coal	13,900
Force of draft:		
Under stack damper	inch water	0.86
Above fire	do	.08
In ash pit (forced draft)		.46
Dry fuel used per square foot of grate surface per hour	pounds	19.63
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.50
Percentage of rated horsepower of boiler developed	do	98.1
Water apparently evaporated per pound of fuel as fired	pounds	6.99
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	do	8.46
Per pound of dry fuel	do	8.92
Per pound of combustible	do	10.33
Efficiency of boiler, including grate	per cent	61.97
Fuel as fired:		
Per indicated horsepower hour	pounds	3.34
Per electrical horsepower hour	do	4.13
Dry fuel:		
Per indicated horsepower hour	do	3.17
Per electrical horsepower hour	do	3.91

Remarks.—Test made on briquets from tests 222 and 223† (equal weights); fuel burned freely with intense heat and no smoke; 47 per cent clinker.

PRODUCER-GAS TEST.

Pennsylvania No. 22 (run of mine).

Test 159.—Duration of test, 50 hours. Average electrical horsepower, 197.7. Average B. t. u. per cubic foot of gas, 145.6. Total coal fired, 11,700 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower-hour (pounds).			
Per electrical horsepower:			
Commercially available	1.23	1.18	1.06
Developed at switchboard	1.18	1.14	1.02
Per brake horsepower:			
Commercially available	1.05	1.00	.90
Developed at engine	1.01	.97	.86
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.31	1.26	1.12
Developed at switchboard	1.26	1.21	1.08
Per brake horsepower:			
Commercially available	1.11	1.07	.95
Developed at engine	1.07	1.03	.92

Analysis of gas by volume. [a]

Carbon dioxide (CO_2)	10.1
Carbon monoxide (CO)	17.6
Hydrogen (H_2)	13.3
Methane (CH_4)	2.2
Nitrogen (N_2)	56.4
Ethylene (C_2H_4)	.4

BRIQUETTING TESTS.

Pennsylvania No. 22 (run of mine).

Tests 211†, 222, and 223†.—Size as used: Over ¼ inch, 1.6 per cent; 1/10 inch to ¼ inch, 17.8 per cent; 1/20 inch to 1/10 inch, 33.4 per cent; 1/40 inch to 1/20 inch, 23.2 per cent; through 1/40 inch, 24 per cent. English briquets with 7 per cent binder showed better outer surface than those with 6 per cent binder. In all briquets surfaces were hard, clean, sharp, and glossy, with characteristic fracture. Renfrow briquets dropped from belt without breakage.

For analyses of briquets see page 221 (those from test 222 under "Steaming test 510").

	Test 211†.	Test 222.	Test 223†.
Details of manufacture:			
Machine used	Renf.	Eng.	Eng.
Temperature of briquets ... °F.	158	185	158
Binder—			
Kind	w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)	4683	4683	4683
Amount ... per cent.	7	7	6
Weight of—			
Fuel briquetted ... pounds.	4,000	19,000	3,200
Briquets, average ... do.	0.442	3.87	3.93
Heat value per pound			
Fuel as received ... B. t. u.	13,311	13,311	13,311
Fuel as fired ... do.	13,561	13,183	13,275
Binder ... do.	16,637	16,637	16,637
Drop test (1-inch screen):			
Help ... per cent.	54.5	79.8	62.2
Passed ... do.	45.5	20.2	37.8
Tumbler test (1-inch screen):			
Held ... do.	85.0	73.7	67.8
Passed (fines) ... do.	15.0	26.3	32.2
Fines through 10-mesh sieve ... do.	90.8	65.0	70.0
Water absorption:			
In 13 days ... do.	11.7	9.6	8.9
Average for first 5 days ... do.	1.78	1.48	1.38
Specific gravity (apparent)	1.110	1.160	1.164

[a] For analyses of fuel used see p. 221 (sample 4498).

Extraction analyses.

	Pitch.	Fuel.	Briquets.		
			Test 211†.	Test 222.	Test 223†.
Labratory No	4683	4650	4684	4704	4706
Air-drying loss ... per cent	.....	0.90	1.10	4.00	2.30
Extracted by CS_2:					
Air-dried ... do	.....	.77	6.85	.....	6.35
As received ... do	89.31	.76	6.77	5.45	6.20
Pitch in briquets as received ... do	.....	.....	6.78	5.30	6.09

RHODE ISLAND.

RHODE ISLAND NO. 1.

Anthracite graphitic coal from Cranston, Providence County (near Providence), was designated Rhode Island No. 1. This sample was mined from surface workings at Cranston, and commercially would be classed as run-of-mine coal. It was shipped under the inspection of J. S. Burrows, and was used in making steaming test 401; also mixed with Utah No. 1 in steaming tests (on briquets) 414 and 415, coking tests 141 and 157 (see p. 263), and briquetting test 127 (see p. 264); mixed with Utah No. 2 in steaming test 416 (on briquets) and briquetting test 133 (see p. 266); mixed with Pennsylvania No. 15 in briquetting test 184† (see p. 204); and mixed with Pennsylvania No. 18 in briquetting test 243† (see pp. 212, 213).

CHEMICAL ANALYSES.

Rhode Island No. 1.

	Car sample.[a]	Steaming tests.[b]			
		401.	414.	415.	416.
Laboratory No	3216	.....	.....	.....	.....
Air-drying loss	2.00	.....	.....	.....	.....
Proximate:					
Moisture	2.41	2.33	2.45	2.27	5.85
Volatile matter	4.92	2.47	24.21	22.20	25.20
Fixed carbon	73.61	78.72	62.60	65.29	59.56
Ash	19.06	16.48	10.74	10.24	9.39
Sulphur	.07	.08	.41	.41	.85
Ultimate:					
Hydrogen	.90	.67	2.95	3.13	2.94
Carbon	75.10	79.49	78.63	77.64	76.42
Nitrogen	.17	.18	.74	.74	.73
Oxygen	4.70	2.71	6.25	7.59	9.04
Ash	.....	16.87	11.01	10.48	9.97
Sulphur	.....	.08	.42	.42	.90
Calorific value (as received):					
Determined ... calories	6,109	.....	.....	.....	.....
Determined ... B. t. u.	10,996	.....	.....	.....	.....
Calculated from ultimate analysis ... calories	6,176	.....	.....	.....	.....
Calculated from ultimate analysis ... B. t. u.	11,117	.....	.....	.....	.....

[a] Sample from producer-gas test 113 (failure) treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Rhode Island No. 1 (briquets).

	Test 401.	Test 414.	Test 415.	Test 416.
Duration of test.....hours..	8.05	5.0	5.0	10.02
Heating value of fuel.....B. t. u. per pound dry fuel..	11,639	12,845	12,823	12,244
Force of draft:				
Under stack damper.....inch water..	0.54	0.67	0.62	0.58
Above fire.....do....	.18	.21	.06	.20
Furnace temperature.....°F..	(a)	.....	2,119	2,053
Dry fuel used per square foot of grate surface per hour.....pounds..	20.22	18.42	19.01	21.51
Equivalent water evaporated per square foot of water-heating surface per hour.....pounds..	1.99	2.96	3.25	2.78
Percentage of rated horsepower of boiler developed.....	55.8	83.0	91.0	78.0
Water apparently evaporated per pound of fuel as fired.....pounds..	4.19	6.75	7.17	4.26
Water evaporated from and at 212 °F.:				
Per pound of fuel as fired.....do....	4.81	7.86	8.36	4.95
Per pound of dry fuel.....do....	4.93	8.05	8.55	5.26
Per pound of combustible.....do....	7.70	9.35	9.75	7.70
Efficiency of boiler, including grate.....per cent..	40.91	60.52	64.39	41.49
Fuel as fired:				
Per indicated horsepower hour.....pounds..	5.88	3.60	3.38	5.71
Per electrical horsepower hour.....do....	7.26	4.44	4.18	7.05
Dry fuel:				
Per indicated horsepower hour.....do....	5.74	3.51	3.31	5.38
Per electrical horsepower hour.....do....	7.08	4.34	4.08	6.64

[a] Too low to be read with Wanner optical pyrometer. Forced draft used on this test.

Remarks.—Tests 414 and 415 on briquets made from Rhode Island No. 1 and Utah No. 1, mixed. (See p. 264.) The briquets burned freely, with short yellow flame; did not crack open, but coked throughout and held together well. No smoke; burned very much like anthracite except for color of flame. These comparative tests on Rhode Island No. 1 coal gave only 55.8 per cent capacity and were unsatisfactory. (See test 401 above.) Heavy clinker, which was tough and plastic when hot and brittle when cold, but did not stick to the grate.

Test 416 on briquets from test 133 made from Rhode Island No. 1 and Utah No. 2, mixed. (See p. 266.) With natural draft the briquets burned with a very short flame; with forced draft they burned with a longer flame, giving a hotter fire. Briquets did not coke or hold together well in the fire. No smoke; see briquetting test 127 (p. 264) for comparative data. No clinker; a large amount of ash resulted, due to the crumbling of the briquets and the falling of the loose particles through the grate.

TENNESSEE.

TENNESSEE NO. 1.

Bituminous coal from Fork Ridge, Claiborne County, on the Louisville and Nashville Railroad, was designated Tennessee No. 1. The coal, as worked at a depth of 52 feet at this place, averages 4 feet 3 inches in thickness.

This sample consisted of run-of-mine coal, was shipped under the supervision of W. J. Von Borries, and was used in making steaming tests 344, 345, and 346; also steaming tests 409 and 411 on briquets made from washed coal; producer-gas test 115; washing test 171; coking tests 133 (raw) and 153 (washed); cupola tests 99, 126, and 128; and briquetting test 130 (washed coal).

Two mine samples were taken for chemical analysis. Sample 2907 was taken 4,000 feet northeast of the slope, where the coal measured 4 feet 4 inches in thickness. Sample 2908 was taken 4,400 feet east of the slope, where the coal measured 4 feet 3 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 1.

	Mine samples.		Car sample.[a]	Steaming tests.[b]				
				344.	345.	346.	409.	411.
Laboratory No.	2907	2908	3016					
Air-drying loss	1.80	1.80	3.00					
Proximate:								
Moisture	3.71	3.66	4.81	4.81	4.06	4.20	2.62	1.99
Volatile matter	35.61	34.58	32.91	32.91	33.80	31.75	37.09	36.56
Fixed carbon	55.94	54.93	51.13	51.13	50.97	50.02	54.32	54.14
Ash	4.74	6.83	11.15	11.15	11.17	14.03	5.97	7.30
Sulphur	1.28	.99	1.58	1.58	1.67	1.45	1.17	1.12
Ultimate:								
Hydrogen			5.13	4.83	4.84	4.68	5.08	4.84
Carbon			69.22	72.72	72.71	70.37	79.02	77.39
Nitrogen			1.60	1.68	1.68	1.63	1.70	1.53
Oxygen			11.32	7.40	7.39	7.17	6.87	7.64
Ash				11.71	11.64	14.64	6.13	7.46
Sulphur				1.66	1.74	1.51	1.20	1.14
Calorific value (as received):								
Determined, calories	7,669		6,983					
Determined, B. t. u.	13,804		12,569					
Calculated from ultimate analysis, calories			6,907					
Calculated from ultimate analysis, B. t. u.			12,433					

[a] Sample from steaming test 344 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 1 (run of mine).

	Test 344.	Test 345.	Test 346.	Test 409.	Test 411.
Size as used:					
Over 3 inches, per cent	38.2	40.8		See p. 228	See p. 228
Over 2 inches, do			43.8		
Over 1 inch, do	24.5	17.1	27.2		
½ inch to 1 inch, do	14.7	19.1	12.4		
¼ inch to ½ inch, do	8.8	9.8	7.4		
Under ¼ inch, do	13.8	13.2	9.2		
Duration of test, hours	10.0	7.28	7.03	10.08	4.48
Heating value of fuel, B. t. u. per pound dry fuel	13,207	13,207	12,773	14,092	13,900
Force of draft:					
Under stack damper, inch water	0.55	0.80	0.74	0.65	0.62
Above fire, do	.15	.18	.20	.13	.10
Furnace temperature, °F.	2,499	2,458	2,393	2,468	2,775
Dry fuel used per square foot of grate surface per hour, pounds	20.81	22.76	22.22	20.02	23.97
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.70	3.98	3.90	3.93	4.80
Percentage of rated horsepower of boiler developed	103.7	111.7	109.5	110.3	134.7
Water apparently evaporated per pound of fuel as fired, pounds	7.05	7.00	7.02	8.23	8.44
Water evaporated from and at 212° F:					
Per pound of fuel as fired, pounds	8.47	8.42	8.43	9.59	9.83
Per pound of dry fuel, do	8.90	8.77	8.80	9.84	10.03
Per pound of combustible, do	10.31	10.23	10.53	10.58	10.93
Efficiency of boiler, including grate, per cent	65.08	64.13	66.53	67.43	69.68
Fuel as fired:					
Per indicated horsepower hour, pounds	3.34	3.36	3.35	2.95	2.88
Per electrical horsepower hour, do	4.12	4.15	4.14	3.64	3.55
Dry fuel:					
Per indicated horsepower hour, do	3.18	3.22	3.21	2.87	2.82
Per electrical horsepower hour, do	3.92	3.94	3.97	3.55	3.48

Remarks.—Tests 409 and 411 on English briquets broken in two, which burned with a long flame and gave a very hot fire, with little smoke. They cracked open to a depth of about 1½ inches, but coked and held together until entirely consumed. No clinker; fine brown ash.

PRODUCER-GAS TEST.

Tennessee No. 1 (run of mine).

Test 115.—Duration of test, 50 hours. Average electrical horsepower, 169. Average B. t. u. per cubic foot of gas, 154.5. Total coal fired, 12,300 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower developed at switchboard	1.46	1.42	1.24
Per brake horsepower developed at engine	1.24	1.20	1.05
Equivalent used by producer plant (pounds).			
Per electrical horsepower developed at switchboard	1.56	1.51	1.32
Per brake horsepower developed at engine	1.32	1.29	1.12

Analyses.

Coal.		*Gas by volume.*	
Moisture	2.72	Carbon dioxide (CO_2)	10.0
Volatile matter	31.81	Carbon monoxide (CO)	19.6
Fixed carbon	53.20	Hydrogen (H_2)	15.3
Ash	12.27	Methane (CH_4)	2.1
Sulphur	1.26	Nitrogen (H_2)	52.6
		Ethylene (C_2H_4)	.4

WASHING AND COKING TESTS.

Tennessee No. 1 (run of mine).

Washing test 171.—Size as used, crushed to 2 inches, jig used, Stewart. Raw coal, 21,600 pounds; washed coal, 18,600 pounds; refuse, 3,000 pounds.

Coking tests.

		Test 133 (raw).	Test 153 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	49	43
Coal charged	pounds	12,000	11,900
Coke produced	do	7,720	7,270
	per cent	64.33	61.09
Breeze produced	pounds	347	273
	per cent	2.89	2.29
Total yield	do	67.22	63.38

Remarks.—Test 133: Light gray and silvery; strong, hard, heavy coke. Test 153: Light gray and silvery; good, strong, heavy coke; washing reduces ash and sulphur.

Analyses.

	Washing test 171.		Coking test 133.		Coking test 153.	
	Raw coal.[a]	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	4.81	5.28	3.71	0.37	4.86	0.93
Volatile matter	32.91	.....	32.81	.73	35.06	.77
Fixed carbon	51.13	.....	51.69	83.00	54.72	89.61
Ash	11.15	5.33	11.79	15.90	5.36	8.69
Sulphur	1.58	1.32	1.58	1.35	1.17	.93

[a] Sample taken from steaming test 344.

Cupola tests of coke made from Tennessee No. 1 coal (washed).

CHARGE.

Cupola test No.	Coke.				Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Phosphorus.	Ratio iron to coke.			1.	2.	3.	4.	5.	
			Per ct.		*Per ct.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
126	133	1.96	0.0238	7	97.22	Coke	190	60	60	60	60	430
						Pig iron	570	420	420	420	420	2,250
						Scrap	190	140	140	140	140	750
99	153	1.87	.0253	7	92.00	Coke	200	57	57	58	58	430
						Pig iron	600	412	412	413	413	2,250
						Scrap	200	137	137	138	138	750
128	153	1.87	.0253	7	99.9	Coke	200	58	58	57	57	430
						Pig iron	600	413	413	412	412	2,250
						Scrap	200	138	138	137	137	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
126	9.58 a. m.	7	10	1,240	244	1,484	33	2,698	4.67	5.80	1,342	112
99	8.47 a. m.	7	7	1,443	563	2,006	34	3,540	6.19	11.60	646	106
128	3.11 p. m.	7	5	1,833	210	2,043	34	3,605	6.57	6.26	769	119

LADLE RECORD.

Ladle No.	Test 126.		Test 99.		Test 128.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).	Pounds.	Time (p. m.).
1	85	10.13	66	9.05	65	3.29
2	95	10.19	59	9.06	110	3.29½
3	98	10.19½	68	9.09	100	3.30
4	82	10.20	61	9.10	75	3.32
5	82	10.22	62	9.11	104	3.32½
6	81	10.22½	51	9.12	117	3.33
7	76	10.23	51	9.13	41	3.35½
8	68	10.28	61	9.14	91	3.36
9	95	10.28½	43	9.15	108	3.36½
10	74	10.29	58	9.16	72	3.38
11	108	10.34	52	9.16½	98	3.39
12	71	10.34½	42	9.17	108	3.40
13	87	10.35	88	9.18	87	3.40½
14	53	10.35½	50	9.19	123	3.41
15	85	10.41	45	9.20	92	3.46
16			73	9.21	93	3.46½
17			43	9.22	92	3.47
18			60	9.23	103	3.49
19			62	9.24	85	3.50
20			35	9.25	69	3.51
21			111	9.26		
22			63	9.27		
23			39	9.27½		
24			100	9.28		

Remarks.—Test 99: Iron very hot. Test 128: Blast off 1 minute.

BRIQUETTING TEST.

Tennessee No. 1 (run of mine).

Test 130.—Size as used: Over $\frac{1}{4}$ inch, 2.5 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 7.7 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 17.8 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 24.1 per cent; through $\frac{1}{40}$ inch, 47.9 per cent. Kind of binder, water-gas pitch (lab. No. 3410, p. 40). Weight of fuel briquetted, 18,600 pounds. B. t. u. per pound of coal as received, 12,569; per pound of briquets as fired, 13,723; per pound of binder, 16,478. Weathering test: Days exposed, 201; condition, B. For analyses of briquets see page 225 (steaming tests 409 and 411).

English briquets with 5 and 6 per cent binder made at 179.6° F., average weight, 3.28 pounds, were good and firm; edges and surfaces harder with 6 per cent than with 5 per cent binder. Fractures of both were sharp and clear. In the drop test with 5 per cent binder the 1-inch screen held 84.4 per cent and passed 15.6 per cent.

Renfrow briquets made at 149° F., average weight 0.5 pound, with 6 and 6.5 per cent binder, showed dull fracture; edges broke easily, surfaces too soft. Those made with 7 per cent binder were satisfactory; fracture clear; edges sharp; briquets broke without crumbling.

Extraction analyses.

	Pitch.	Fuel.	Briquets test 130.
Laboratory No.	3410		
Air-drying loss ... per cent		3.50	1.00
Extracted by CS_2:			
Air dried ... do		2.23	4.59
As received ... do	79.98	2.15	4.54
Pitch in briquets as received ... do			3.07

TENNESSEE NO. 2.

Bituminous coal from a mine located 2½ miles northeast of Gatliff, Campbell County, on the Louisville and Nashville Railroad, was designated Tennessee No. 2. The coal, as worked from the outcrop at this place, averages 3 feet 6 inches in thickness.

This sample, consisting of run-of-mine coal loaded under the supervision of John W. Groves, was used in making steaming tests 367, 368, and 369; producer-gas test 107; coking test 127, and cupola tests 100 and 140.

Two mine samples were taken for chemical analyses. Sample 2931 was taken 687 feet northeast of the opening, where the coal measured 3 feet 8 inches in thickness. Sample 2932 was taken 675 feet south of the opening, where the coal measured 3 feet 7 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 2.

	Mine samples.		Car samples.[a]	Steaming tests.[b]		
				367.	368.	369.
Laboratory No	2931	2932	3129			
Air-drying loss	1.50	1.20	3.20			
Proximate:						
Moisture	3.61	3.19	5.09	4.68	5.09	5.17
Volatile matter	37.29	38.08	35.79	36.00	35.79	35.55
Fixed carbon	55.69	56.35	52.31	53.39	52.31	52.85
Ash	3.41	2.38	6.81	5.93	6.81	6.43
Sulphur	.83	.88	.98	.98	.98	.95
Ultimate:						
Hydrogen			5.39	5.13	5.08	5.10
Carbon			73.54	78.28	77.48	77.84
Nitrogen			1.75	1.87	1.84	1.86
Oxygen			11.53	7.47	7.39	7.42
Ash				6.22	7.18	6.78
Sulphur				1.03	1.03	1.00
Calorific value (as received):						
Determined, calories	7,850		7,386			
Determined, B. t. u.	14,130		13,295			
Calculated from ultimate analysis, calories			7,325			
Calculated from ultimate analysis, B. t. u.			13,185			

[a] Sample from steaming test 368 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample

STEAMING TESTS.

Tennessee No. 2 (run of mine).

	Test 367.[a]	Test 368.	Test 369.
Size as used:			
Over 1 inch ... per cent	43.2	42.8	49.4
½ inch to 1 inch ... do	23.9	18.4	22.4
¼ inch to ½ inch ... do	13.0	12.2	11.8
Under ¼ inch ... do	19.9	26.6	16.4
Duration of test ... hours	9.97	9.98	9.97
Heating value of coal ... B. t. u. per pound dry coal	14,153	14,008	14,069
Force of draft:			
Under stack damper ... inch water	0.68	0.48	0.33
Above fire ... do	.19	.11	.08
Furnace temperature ... °F	2,788	2,488	2,250
Dry coal used per square foot of grate surface per hour ... pounds	26.41	19.16	15.24
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	4.63	3.65	2.93
Percentage of rated horsepower of boiler developed	129.9	102.3	82.3
Water apparently evaporated per pound of coal as fired ... pounds	7.10	7.63	7.75
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	8.38	9.06	9.14
Per pound of dry coal ... do	8.79	9.54	9.64
Per pound of combustible ... do	9.46	10.52	10.57
Efficiency of boiler, including grate ... per cent	59.98	65.77	66.17
Coal as fired:			
Per indicated horsepower hour ... pounds	3.37	3.12	3.09
Per electrical horsepower hour ... do	4.17	3.85	3.82
Dry coal:			
Per indicated horsepower hour ... do	3.22	2.96	2.93
Per electrical horsepower hour ... do	3.97	3.66	3.62

[a] Test run for maximum capacity.

PRODUCER-GAS TEST.

Tennessee No. 2 (run of mine).

Test 107.—Duration of test, 50 hours. Average electrical horsepower, 201.3. Average B. t. u. per cubic foot of gas, 167.9. Total coal fired, 11,250 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.18	1.14	1.08
Developed at switchboard	1.12	1.08	1.03
Per brake horsepower:			
Commercially available	1.00	.97	.92
Developed at engine	.95	.92	.87
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.30	1.26	1.20
Developed at switchboard	1.24	1.20	1.14
Per brake horsepower:			
Commercially available	1.11	1.07	1.02
Developed at engine	1.05	1.02	.96

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.40	Carbon dioxide (CO_2)	10.9
Volatile matter	37.58	Carbon monoxide (CO)	18.8
Fixed carbon	54.27	Hydrogen (H_2)	18.6
Ash	4.75	Methane (CH_4)	2.2
Sulphur	.83	Nitrogen (N_2)	49.0
		Ethylene (C_2H_4)	.5

COKING TEST.

Tennessee No. 2 (run of mine).

Test 127.—Size as used: Raw, finely crushed. Duration of test, 54 hours. Coal charged, 12,000 pounds. Coke produced, 7,213 pounds; 60.11 per cent. Breeze produced, 343 pounds; 2.86 per cent. Total yield, 62.97 per cent. Fine-fingered coke; very brittle and breaks very easily on handling; light gray, with large carbon deposit.

Analyses.

	Coal.	Coke.
Moisture	3.56	1.13
Volatile matter	36.53	.63
Fixed carbon	55.32	91.00
Ash	4.59	7.23
Sulphur	.95	.78

Cupola tests of coke made from Tennessee No. 2 coal.

CHARGE.

Cupola test No.	Coke.[a] Test No.	Coke.[a] Specific gravity.	Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
100	127	1.81	1 to 7	99.9	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
140	127	1.81	1 to 7	94.44	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

[a] Phosphorus in coke, 0.0094 per cent.

Cupola tests of coke made from Tennessee No. 2 coal—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
100	1.20 p. m....	7	7	1,551	556	2,107	33	3,830	5.79	6.46	699	66
140	2.47 p. m....	7	6	2,080	270	2.350	34	4,147	5.97	5.77	477	36

LADLE RECORD.

Ladle No.	Test 100.		Test 140.		Ladle No.	Test 100.		Test 140.	
	Pounds.	Time (p. m.).	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).	Pounds.	Time (p. m.).
1.....	52	1.35	28	2.59	14.....	51	1.49	107	3.15½
2.....	34	1.35½	110	3.01	15.....	61	1.50	61	3.16
3.....	64	1.40	44	3.01½	16.....	53	1.50½	80	3.18
4.....	70	1.40½	90	3.04	17.....	50	1.51	111	3.18½
5.....	52	1.41	78	3.07	18.....	81	1.52	57	3.19
6.....	94	1.42	106	3.07½	19.....	58	1.52½	79	3.21
7.....	79	1.42½	102	3.08	20.....	46	1.53	108	3.21½
8.....	73	1.43	80	3.10	21.....	82	1.55	71	3.22
9.....	80	1.45½	101	3.10½	22.....	49	1.55½	77	3.23
10.....	67	1.46	82	3.11	23.....	49	1.56	101	3.23½
11.....	60	1.46½	83	3.13	24.....	60	1.59	57	3.24
12.....	68	1.48	78	3.13½	25.....	58	2.00	63	3.26½
13.....	60	1.48½	83	3.15	26.....	.....	.....	43	3.27

Remarks.—Test 100: Iron very hot and fluid. Test 140: Iron medium.

TENNESSEE NO. 3.

Bituminous coal from Gatliffe, Campbell County, on the Louisville and Nashville Railroad, was designated Tennessee No. 3. The coal, as worked at the outcrop at this place, averages 4 feet 6 inches in thickness.

This sample, consisting of run-of-mine coal, shipped under the supervision of John W. Groves, was used in making steaming tests 349 and 350; producer-gas test 106; coking test 128, and cupola tests 104 and 139.

Two mine samples were taken for chemical analysis. Sample 2929 was taken 500 feet south of the drift mouth, where the coal measured 5 feet 2 inches in thickness. Sample 2930 was taken 1,050 feet southwest of the drift mouth, where the coal measured 4 feet 5½ inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 3.

	Mine samples.		Car samples.[a]	Steaming tests.[b]	
				349.	350.
Laboratory No.	2929	2930	3040		
Air-drying loss	1.80	1.90	3.20		
Proximate:					
Moisture	4.25	4.42	5.38	5.38	6.47
Volatile matter	35.31	35.35	34.54	34.54	33.92
Fixed carbon	56.31	57.53	53.03	53.03	52.13
Ash	4.13	2.70	7.05	7.05	7.48
Sulphur	.93	.80	.99	.99	1.13
Ultimate:					
Hydrogen			5.50	5.18	5.14
Carbon			72.41	76.52	75.93
Nitrogen			1.72	1.82	1.81
Oxygen			12.33	7.98	7.91
Ash				7.45	8.00
Sulphur				1.05	1.21
Calorific value (as received):					
Determined, calories	7,502		7,249		
Determined, B. t. u.	13,666		13,048		
Calculated from ultimate analysis, calories			7,238		
Calculated from ultimate analysis, B. t. u.			13,028		

[a] Sample from steaming test 349 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 3 (run of mine).

	Test 349.	Test 350.
Size as used:		
Over 3 inches, per cent	67.8	59.1
Over 1 inch, do	19.3	20.0
½ inch to 1 inch, do	5.4	9.1
¼ inch to ½ inch, do	2.7	4.6
Under ¼ inch, do	4.8	7.2
Duration of test, hours	8.97	10.0
Heating value of coal, B. t. u. per pound dry coal	13,788	13,689
Force of draft:		
Under stack damper, inch water	0.57	0.80
Above fire, do	.14	.14
Furnace temperature, °F.	2,664	2,562
Dry coal used per square foot of grate surface per hour, pounds	21.70	21.63
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.75	4.07
Percentage of rated horsepower of boiler developed	105.0	114.0
Water apparently evaporated per pound of coal as fired, pounds	6.81	7.31
Water evaporated from and at 212° F.:		
Per pound of coal as fired, do	8.18	8.82
Per pound of dry coal, do	8.65	9.43
Per pound of combustible, do	9.49	10.35
Efficiency of boiler, including grate, per cent	60.58	66.52
Coal as fired:		
Per indicated horsepower hour, pounds	3.46	3.21
Per electrical horsepower hour, do	4.27	3.96
Dry coal:		
Per indicated horsepower hour, do	3.27	3.00
Per electrical horsepower hour, do	4.04	3.70

PRODUCER-GAS TEST.

Tennessee No. 3 (run of mine).

Test 106.—Duration of test, 50 hours. Average electrical horsepower, 201. Average B. t. u. per cubic foot of gas, 159.7. Total coal fired, 12,950 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.38	1.31	1.22
Developed at switchboard	1.29	1.23	1.14
Per brake horsepower:			
Commercially available	1.17	1.11	1.04
Developed at engine	1.10	1.04	.97
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.50	1.42	1.32
Developed at switchboard	1.40	1.33	1.24
Per brake horsepower:			
Commercially available	1.27	1.21	1.12
Developed at engine	1.19	1.13	1.05

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.88	Carbon dioxide (CO_2)	9.8
Volatile matter	34.84	Carbon monoxide (CO)	20.2
Fixed carbon	53.57	Hydrogen (H_2)	16.5
Ash	6.71	Methane (CH_4)	2.4
Sulphur	1.16	Nitrogen (N_2)	50.7
		Ethylene (C_2H_4)	.4

COKING TEST.

Tennessee No. 3 (run of mine).

Test 128.—Size as used: Raw, finely crushed. Duration of test, 42 hours. Coal charged, 11,280 pounds. Coke produced, 7,136 pounds; 63.26 per cent. Breeze produced, 394 pounds; 3.49 per cent. Total yield, 66.75 per cent. Fingered coke; light gray, with large deposit of carbon.

Analyses.

	Coal.	Coke.
Moisture	4.32	0.67
Volatile matter	33.90	.81
Fixed carbon	55.56	87.44
Ash	6.22	11.08
Sulphur	1.05	.88

Cupola tests of coke made from Tennessee No. 3 coal.

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
104	128	1.87	7	95.83	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
139	128	1.87	7	97.81	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

[a] Phosphorus in coke, 0.0125 per cent.

Cupala tests of coke made from Tennessee No. 3 coal—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
104	9.08 a. m...	7½	8	1,477	429	1,906	35	3,267	5.51	7.93	856	84
139	10.43 a. m...	6½	9	1,913	239	2,152	32	4,035	5.55	6.60	650	50

LADLE RECORD.

Ladle No.	Test 104.		Test 139.		Ladle No.	Test 104.		Test 139.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).	Pounds.	Time (a. m.).
1.....	50	9.21	93	10.56	15.....	36	9.40	76	11.17
2.....	64	9.21½	93	10.59	16.....	101	9.40½	115	11.17½
3.....	62	9.22	100	10.59½	17.....	39	9.41	110	11.18
4.....	77	9.24	81	11.02	18.....	42	9.42	65	11.23
5.....	82	9.25	62	11.02½	19.....	77	9.42½	112	11.23½
6.....	20	9.25½	89	11.06	20.....	41	9.43	115	11.24
7.....	57	9.31	81	11.06½	21.....	38	9.44	.....	.....
8.....	68	9.31½	101	11.07	22.....	74	9.44½	.....	.....
9.....	64	9.32	87	11.09	23.....	24	9.45	.....	.....
10.....	61	9.36	117	11.09½	24.....	29	9.48	.....	.....
11.....	50	9.36½	108	11.10	25.....	63	9.48½	.....	.....
12.....	42	9.37	85	11.13	26.....	27	9.49	.....	.....
13.....	84	9.38	122	11.13½	27.....	62	9.51	.....	.....
14.....	43	9.38½	101	11.14					

Remarks.—Test 104: Iron hot and fluid. Test 139: Iron hot.

TENNESSEE NO. 4.

Bituminous coal from a mine located 3 miles north of Oliver Springs, Roane County, on the Louisville and Nashville Railroad, was designated Tennessee No. 4. The coal, as worked at the outcrop at this place, averages 4 feet 8 inches in thickness.

This sample, consisting of run-of-mine coal, loaded under the supervision of John W. Groves, was used in making steaming tests 355, 356, and (on briquets) 405; producer-gas test 111; coking tests 125 and 129; cupola tests 102, 105, and 138; and briquetting tests 120 and (mixed with miscellaneous No. 5, p. 292) 150 and 151.

Two mine samples were taken for chemical analysis. Sample 2956 was taken 1,300 feet northeast of the drift mouth, where the coal measured 4 feet 5½ inches in thickness. Sample 2957 was taken 2,000 feet south of the drift mouth, where the coal measured 5 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 4.

	Mine samples.		Car sample.[a]	Steaming tests.[b]			Briquetting tests.[c]	
				355.	356.	405.	150.	151.
Laboratory No.	2956	2957	3058				3380	3367
Air-drying loss	1.90	1.70	4.70					
Proximate:								
Moisture	3.25	3.12	6.39	6.39	5.72	2.88	2.55	2.71
Volatile matter	35.63	35.15	32.32	32.32	31.78	35.78	31.91	29.56
Fixed carbon	54.51	55.52	51.76	51.76	51.91	53.84	57.42	58.41
Ash	6.61	6.21	9.53	9.53	10.59	7.50	8.12	9.32
Sulphur	.85	.86	.98	.98	.92	.91	.92	.93
Ultimate:								
Hydrogen			5.41	5.02	4.96	4.73	4.34	4.15
Carbon			70.16	74.95	74.13	77.93	78.53	78.40
Nitrogen			1.56	1.67	1.64	1.79	1.71	1.67
Oxygen			12.36	7.13	7.06	6.89	6.15	5.60
Ash				10.18	11.23	7.72	8.33	9.58
Sulphur				1.05	.98	.94	.94	.96
Calorific value (as received):								
Determined, calories	7,508		6,988					
Determined, B. t. u.	13,514		12,578					
Calculated from ultimate analysis, calories			7,023					
Calculated from ultimate analysis, B. t. u.			12,641					

[a] Sample from steaming test 355 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[c] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Tennessee No. 4 (run of mine).

	Test 355.	Test 356.[a]	Test 405.
Size as used:			
Over 1 inch, per cent	20.1	32.0	See p. 238
½ inch to 1 inch, do	25.2	19.6	
¼ inch to ½ inch, do	21.6	19.0	
Under ¼ inch, do	33.1	29.4	
Duration of test, hours	10	9.97	8.25
Heating value of fuel, B. t. u. per pound dry fuel	13,441	13,288	13,936
Force of draft:			
Under stack damper, inch water	0.74	0.76	0.64
Above fire, do	.16	.22	.18
Furnace temperature, °F	2,584	2,719	2,294
Dry fuel used per square foot of grate surface per hour, pounds	21.49	24.34	19.16
Equivalent water evaporated per square foot of water-heating surface, per hour, pounds	3.95	4.48	3.76
Percentage of rated horsepower of boiler developed	110.8	125.6	105.3
Water apparently evaporated per pound of fuel as fired, pounds	7.36	7.48	8.22
Water evaporated from and at 212° F.:			
Per pound of fuel as fired, do	8.62	8.69	9.54
Per pound of dry fuel, do	9.21	9.22	9.82
Per pound of combustible, do	10.39	10.53	10.79
Efficiency of boiler, including grate, per cent	66.17	67.01	68.05
Fuel as fired:			
Per indicated horsepower hour, pounds	3.28	3.25	2.96
Per electrical horsepower hour, do	4.05	4.02	3.66
Dry fuel:			
Per indicated horsepower hour, do	3.07	3.07	2.88
Per electrical horsepower hour, do	3.79	3.79	3.55

[a] Test made for maximum capacity.

Remarks.—Test 405 on briquets, which burned with a long flame and cracked open to a depth of three-fourths inch; coked and held together until entirely consumed; made very little smoke. Fine gray ash of medium weight, with very little green coal, loss of coal falling through grate and over bridge wall being very small.

PRODUCER-GAS TEST.

Tennessee No. 4 (run of mine).

Test 111.—Duration of test, 50 hours. Average electrical horsepower, 182. Average B. t. u. per cubic foot of gas, 161.7. Total coal fired, 12,150 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.42	1.37	1.27
Developed at switchboard	1.34	1.29	1.19
Per brake horsepower:			
Commercially available	1.21	1.17	1.08
Developed at engine	1.13	1.10	1.01
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.54	1.49	1.38
Developed at switchboard	1.45	1.40	1.29
Per brake horsepower:			
Commercially available	1.31	1.27	1.17
Developed at engine	1.23	1.19	1.10

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.29	Carbon dioxide (CO_2)	10.4
Volatile matter	34.49	Carbon monoxide (CO)	19.0
Fixed carbon	54.82	Hydrogen (H_2)	16.7
Ash	7.40	Methane (CH_4)	2.4
Sulphur	.88	Nitrogen (N_2)	51.0
		Ethylene (C_2H_4)	.5

COKING TESTS.

Tennessee No. 4 (run of mine).

		Test 125.	Test 129.
Size as used		f. c.	f. c.
Duration of test	hours	60	53
Coal charged	pounds	12,000	11,270
Coke produced	do	7,471	7,500
	per cent	62.26	66.55
Breeze produced	pounds	313	266
	per cent	2.61	2.36
Total yield	do	64.87	68.91

Remarks.—Test 125: Light gray and silvery color; fingered coke ¾-inch black butts; ash somewhat high; better coke probably from washed coal. Test 129: Light gray and silvery; fingered coke; black butts removed; heavier and better than coke of test 125; resultant coke probably improved by washing.

Analyses.

	Coal.	Coke.	
		Test 125.	Test 129.
Moisture	3.82	0.54	1.43
Volatile matter	33.17	1.56	0.28
Fixed carbon	53.17	84.27	86.73
Ash	9.84	13.63	11.56
Sulphur	.89	.72	.69

Cupola tests of coke made from Tennessee No. 4 coal.

CHARGE.

Cupola test No.	Coke.[a] Test No.	Specific gravity.	Phosphorus.	Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
			Per ct.		*Per ct.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
102	125	1.93	0.0215	7	98.61	Coke	190	60	60	60	60	430
						Pig iron	570	420	420	420	420	2,250
						Scrap	190	140	140	140	140	750
105	129	1.91	.0233	7	99.0	Coke	190	60	60	60	60	430
						Pig iron	570	420	420	420	420	2,250
						Scrap	190	140	140	140	140	750
138	129	1.91	.0233	7	94.44	Coke	190	60	60	60	60	430
						Pig iron	570	420	420	420	420	2,250
						Scrap	190	140	140	140	140	750

a Sulphur in ash, test 102, 0.03 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure. On at—	Maximum.	Iron running in—	Weight of iron. Poured.	Additional melted.	Total.	Melting. Time.	Rate per hour.	Ratio iron to coke.	Loss.	Recovered. Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
102	3.15 p. m.	7	8	1,731	219	1,950	32	3,656	5.57	6.60	852	79
105	2.25 p. m.	7½	7	1,915	131	2,046	31	3,960	5.81	6.70	753	78
138	3.51 p. m.	7	9	1,875	252	2,127	40	3,191	6.09	6.16	688	81

LADLE RECORD.

Ladle No.	Test 102. Pounds.	Time (p. m.).	Test 105. Pounds.	Time (p. m.).	Test 138. Pounds.	Time (p. m.).
1	104	3.32	94	2.38	87	4.03
2	62	3.32½	98	2.38½	73	4.06
3	95	3.35	48	2.39	84	4.06½
4	79	3.35½	89	2.42	46	4.07
5	86	3.38	111	2.43	89	4.09
6	22	3.38½	113	2.43½	79	4.11
7	79	3.40	87	2.46	106	4.11½
8	91	3.41½	104	2.46½	60	4.12
9	76	3.42	97	2.47	98	4.14
10	107	3.45	95	2.48	31	4.14½
11	107	3.45½	98	2.48½	78	4.18
12	81	3.46	89	2.50	116	4.18½
13	103	3.48	88	2.51	93	4.19
14	110	3.48½	91	2.51½	71	4.23
15	55	3.49	105	2.53	92	4.23½
16	103	3.50	34	2.54	122	4.24
17	84	3.51	91	2.56	92	4.28
18	74	3.54	100	2.57½	102	4.28½
19	108	3.54½	86	2.58	77	4.29
20	105	3.55	70	3.00	103	4.32
21			127	3.03	26	4.32½
22					74	4.35
23					27	4.35½
24					49	4.40

Remarks.—Tests 102 and 138: Iron hot. Test 105: Iron very hot and fluid.

BRIQUETTING TESTS.

Tennessee No. 4 (run of mine).

Test 120.—English briquets made at 179.6° F., average weight 3.3 pounds, with 5 per cent binder, were easily broken, showing cracks with soft edges; those made with 5.5 per cent binder showed improvement, but the edges were not sharp, and the

briquets were easily broken; those with 6 per cent binder were satisfactory, showing firm edges, hard surfaces, and clean, sharp fracture; those with 6.5 per cent binder showed improvement on surfaces and edges. In the drop test with briquets containing 5 per cent binder the 1-inch screen held 83.3 per cent and passed 15.7 per cent; with 5.5 per cent binder 85.4 per cent was held and 14.6 per cent passed. Renfrow briquets made at 149° F., average weight 0.4 pound, with 6, 6.5, and 7 per cent binder, had smooth, firm surfaces and edges slightly soft, though generally satisfactory; 7.5 per cent binder made the best briquets of the lot; all surfaces and fractures were entirely satisfactory. For analyses of briquets see page 235 (steaming test 405).

Test 150.—Tennessee No. 4, 80 per cent; miscellaneous No. 5 (coke breeze, p. 292) 20 per cent. Briquets with 8 per cent binder were satisfactory, with no difference in appearance from those made from Tennessee No. 4 alone. They were tough when warm, easily handled and stored, and had rough but hard surfaces. The briquets were difficult to break; the fracture was uneven, although the edges were firm. The structure was porous.

Test 151.—Tennessee No. 4, 75 per cent; miscellaneous No. 5, 25 per cent. With the increased percentage of coke breeze (see test 150) the briquets were easily broken when warm, although sufficiently tough after cooling.

		Test 120.	Test 150.	Test 151.
Size as used:				
Over ¼ inch	per cent	3.2	3.2	3.2
1/16 inch to ¼ inch	do	11.4	10.9	10.9
3/16 inch to 1/16 inch	do	19.9	18.6	18.6
1/16 inch to 3/16 inch	do	25.0	25.8	25.8
Under 1/16 inch	do	40.0	41.5	41.5
Details of manufacture:				
Machine used		(a)	Renf.	Renf.
Temperature of briquets	°F.	(a)	149	149
Binder—				
Kind		w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)		3410	3410	3410
Amount	per cent	(a)	8	8
Weight of—				
Fuel briquetted		44,000	40,000	40,000
Briquets, average		(a)	.532	.513
Heat value per pound—				
Fuel as received: Tennessee No. 4	B. t. u.	12,578	12,578	12,576
Fuel as received: Miscellaneous No. 5	do	.....	11,036	11,036
Fuel as fired	do	13,578	13,536	13,154
Binder	do	16,478	16,478	16,478
Weathering test:				
Time exposed	days	214	214	214
Condition		B.	B.	B.

a See notes preceding table.

Extraction analyses.

		Fuels.		Briquets.		
	Pitch.	Tenn. No. 4.	Misc. No. 5.	Test 120.	Test 150.	Test 151.
Laboratory No.	3410	3058	3366	.....	3380	3367
Air-drying loss, per cent	.....	4.70	8.70	1.10	0.60	0.60
Extracted by CS_2:						
Air-dried, do	.....	1.50	.65	5.82	6.27	6.56
As received, do	79.98	1.38	.59	5.75	6.23	6.52
Pitch in briquets as received, do	.....	.....	.....	5.56	7.29	7.51

TENNESSEE NO. 5.

Bituminous coal from Petros, Morgan County, on the Southern Railway, was designated Tennessee No. 5. The coal, as worked from *the outcrop* at this place, averages 2 feet 10 inches in thickness.

This sample, consisting of run-of-mine coal inspected and loaded under the supervision of John W. Groves, was used in making steaming tests 352, 357, and 358; producer-gas test 125; washing test 172; coking test 154 (washed coal); and cupola tests 106 and 129.

Two mine samples were taken for chemical analysis. Sample 2958 was taken 2,500 feet southeast of the drift mouth, where the coal measured 2 feet 8½ inches in thickness. Sample 2959 was taken 3,800 feet east of the drift mouth, where the coal measured 3 feet ½ inch in thickness.

CHEMICAL ANALYSES.

Tennessee No. 5.

	Mine samples.		Car samples.[a]	Steaming tests.[b]		
				352.	357.	358.
Laboratory No	2958	2959	3050			
Air-drying loss	1.30	0.90	4.30			
Proximate:						
Moisture	2.25	2.20	5.59	5.59	5.82	6.73
Volatile matter	35.37	36.76	33.62	33.62	33.59	32.84
Fixed carbon	55.47	52.84	51.03	51.03	51.73	51.12
Ash	6.91	8.20	9.76	9.76	8.86	9.31
Sulphur	2.96	3.84	3.23	3.33		2.95
Ultimate:						
Hydrogen			5.24	4.89	4.89	4.93
Carbon			70.08	74.23	74.23	74.76
Nitrogen			1.62	1.72	1.72	1.73
Oxygen			10.07	5.40	5.40	5.44
Ash				10.34	10.34	9.98
Sulphur				3.42	3.42	3.16
Calorific value (as received):						
Determined, calories	7,695		7,135			
Determined, B. t. u.	13,851		12,841			
Calculated from ultimate analysis, calories			7,107			
Calculated from ultimate analysis, B. t. u.			12,793			

[a] Sample from steaming test 352 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 5 (run of mine).

	Test 352.	Test 357.	Test 358.
Size as used:			
Over 1 inch, per cent	29.1	12.9	19.9
½ inch to 1 inch, do	17.3	25.8	28.2
¼ inch to ½ inch, do	20.9	21.9	20.6
Under ¼ inch, do	32.7	39.4	31.3
Average diameter, inch	.86	.58	.69
Duration of test, hours	9.98	10.00	10.00
Heating value of coal, B. t. u. per pound dry coal	13,604	13,792	13,685
Force of draft:			
Under stack damper, inch water	0.62	0.74	0.75
Above fire, do	.13	.21	.20
Furnace temperature, °F	2,456	2,575	2,520
Dry coal used per square foot of grate surface per hour, pounds	18.89	22.49	22.12
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.40	3.97	4.12
Percentage of rated horsepower of boiler developed	95.4	111.2	115.5
Water apparently evaporated per pound of coal as fired, pounds	7.08	7.14	7.49
Water evaporated from and at 212° F.:			
Per pound of coal as fired, do	8.52	8.33	8.69
Per pound of dry coal, do	9.02	8.84	9.32
Per pound of combustible, do	10.31	9.89	10.52
Efficiency of boiler, including grate, per cent	64.03	61.80	65.77
Coal as fired:			
Per indicated horsepower hour, pounds	3.32	3.39	3.25
Per electrical horsepower hour, do	4.10	4.19	4.02
Dry coal:			
Per indicated horsepower hour, do	3.13	3.20	3.03
Per electrical horsepower hour, do	3.87	3.95	3.75

PRODUCER-GAS TEST.

Tennessee No. 5 (run of mine).

Test 125.—Duration of test, 50 hours. Average electrical horsepower, 186.7. Average B. t. u. per cubic foot of gas, 142.1. Total coal fired, 12,900 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.48	1.44	1.31
Developed at switchboard	1.38	1.35	1.23
Per brake horsepower:			
Commercially available	1.26	1.23	1.11
Developed at engine	1.18	1.15	1.04
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.61	1.57	1.43
Developed at switchboard	1.51	1.47	1.34
Per brake horsepower:			
Commercially available	1.37	1.34	1.24
Developed at engine	1.28	1.25	1.14

Analyses.

Coal.		*Gas by volume.*	
Moisture	2.54	Carbon dioxide (CO_2)	11.3
Volatile matter	34.64	Carbon monoxide (CO)	17.0
Fixed carbon	53.96	Hydrogen (H_2)	15.3
Ash	8.86	Methane (CH_4)	1.7
Sulphur	3.39	Nitrogen (N_2)	54.2
		Ethylene (C_2H_4)	.5

WASHING AND COKING TESTS.

Washing test 172.—Size as used: Crushed to 2 inches. Jig used, Stewart. Raw coal, 18,450 pounds; washed, 16,000 pounds; refuse, 2,450 pounds.

Coking test 154.—Size as used: Washed, finely crushed. Duration of test, 49 hours. Coal charged, 11,570 pounds. Coke produced, 6,807 pounds, 58.83 per cent. Breeze produced, 354 pounds, 2.20 per cent. Total yield, 61.03 per cent. Light gray and silvery. Good, strong, heavy coke. High sulphur not removed by washing.

Analyses.

	Washing test 172.		Coking test 154.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	5.59	5.29	5.53	0.56
Volatile matter	33.62	.....	35.06	.42
Fixed carbon	51.03	.....	53.28	90.46
Ash	9.76	5.64	6.13	8.56
Sulphur	3.23	2.46	2.44	2.08

Cupola tests of coke made from Tennessee No. 5 coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
106	154	1.91	7	98.51	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
129	154	1.91	7	93.05	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
106	9.13	7	7	2,328	144	2,472	31	4,784	6.92	8.30	279	73
129	9.44	7	6	1,825	418	2,243	34	3,958	6.30	6.13	573	74

LADLE RECORD.

Ladle No.	Test 106.		Test 129.		Ladle No.	Test 106.		Test 129.	
	Pounds.	Time (a. m.).	Pounds.	Time (a. m).		Pounds.	Time (a. m.).	Pounds.	Time (a. m.).
1	103	9.25	80	9.58	13	111	9.38½	80	10.14
2	107	9.25½	65	9.59	14	103	9.39	104	10.14½
3	80	9.26	91	10.05	15	88	9.40	78	10.15½
4	86	9.29	64	10.06	16	111	9.40½	115	10.16
5	109	9.30	87	10.09	17	111	9.41	108	10.16½
6	116	9.31	88	10.09½	18	98	9.42	84	10.17
7	89	9.32	64	10.10	19	101	9.42½	83	10.17½
8	108	9.32½	76	10.11½	20	97	9.43	32	10.18
9	89	9.35	84	10.12	21	74	9.46	90	10.23
10	81	9.35½	102	10.12½	22	105	9.46	75	10.24
11	100	9.36	95	10.13	23	124	9.47	.....	.....
12	87	9.38	80	10.13½	24	50	9.51	.....	.....

Remarks.—Test 106: Iron very hot and fluid.

TENNESSEE NO. 6.

Bituminous coal from a mine located 3 miles northwest of Waldensia, Cumberland County, on the Southern Railway, was designated Tennessee No. 6. The coal, as worked from the outcrop at this place, averages 4 feet in thickness.

The sample, consisting of run-of-mine coal inspected by John W. Groves, was used in making steaming tests 379, 380, and 381; producer-gas test 110; coking test 122; and cupola tests 112 and 141.

Two mine samples were taken for chemical analysis. Sample 2977 was taken 200 feet west of the drift mouth, where the coal measured 3 feet 6 inches in thickness. Sample 2978 was taken 350 feet northeast of the drift mouth, where the coal measured 4 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 6.

	Mine samples.		Car sample.	Steaming tests.[a]		
				379.	380.	381.
Laboratory No.	2977	2978	3102	.....	.....	.....
Air-drying loss	2.70	1.90	2.90	.....	.....	.....
Proximate:						
Moisture	3.80	3.00	3.89	2.74	3.18	3.16
Volatile matter	30.72	30.88	27.61	26.95	27.21	26.77
Fixed carbon	60.98	59.96	54.07	51.77	53.93	52.27
Ash	4.50	6.16	14.43	18.54	15.68	17.80
Sulphur	.78	1.08	.78	.74	.77	.75
Ultimate:						
Hydrogen	.....	.....	4.84	4.37	4.52	4.41
Carbon	.....	.....	70.04	69.42	71.88	69.98
Nitrogen	.....	.....	.98	.98	1.00	.98
Oxygen	.....	.....	8.93	5.41	5.61	5.47
Ash	.....	.....	.....	19.06	16.19	18.38
Sulphur	.....	.....	.....	.76	.80	.78
Calorific value (as received):						
Determined, calories	7,879	.....	6,952	.....	.....	.....
Determined, B. t. u.	14,182	.....	12,514	.....	.....	.....
Calculated from ultimate analysis, calories	.....	.....	6,959	.....	.....	.....
Calculated from ultimate analysis, B. t. u.	.....	.....	12,526	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 6 (run of mine).

	Test 379.	Test 380.	Test 381.
Size as used:			
Over 1 inch ... per cent	27.7	.....	21.7
½ inch to 1 inch ... do	27.8	.....	17.4
¼ inch to ½ inch ... do	19.8	.....	19.6
Under ¼ inch ... do	24.7	.....	41.3
Duration of test ... hours	9.88	10.03	10.02
Heating value of coal ... B. t. u. per pound dry coal	12,406	12,839	12,505
Force of draft:			
Under stack damper ... inch water	0.59	0.67	0.70
Above fire ... do	.14	.19	.19
Dry coal used per square foot of grate surface per hour ... pounds	18.42	18.57	18.35
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.25	[a] 2.98	2.88
Percentage of rated horsepower of boiler developed	9.12	[a] 8.35	80.7
Water apparently evaporated per pound of coal as fired ... pounds	7.30	[a] 6.59	6.42
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	8.61	[a] 7.78	7.61
Per pound of dry coal ... do	8.85	[a] 8.04	7.86
Per pound of combustible ... do	11.29	[a] 9.87	10.04
Efficiency of boiler, including grate ... per cent	68.87	[a] 60.47	60.70
Coal as fired:			
Per indicated horsepower hour ... pounds	3.28	[a] 3.63	3.72
Per electrical horsepower hour ... do	4.05	[a] 4.49	4.59
Dry coal:			
Per indicated horsepower hour ... do	3.20	[a] 3.52	3.60
Per electrical horsepower hour ... do	3.94	[a] 4.34	4.44

[a] Questionable.

PRODUCER-GAS TEST.

Tennessee No. 6 (run of mine).

Test 110.—Duration of test, 30 hours. Average electrical horsepower, 156. Average B. t. u. per cubic foot of gas, 133.3. Total coal fired, 7,950 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.84	1.78	1.40
Developed at switchboard	1.70	1.64	1.28
Per brake horsepower:			
Commercially available	1.56	1.51	1.19
Developed at engine	1.45	1.39	1.10
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.02	1.95	1.53
Developed at switchboard	1.87	1.80	1.42
Per brake horsepower:			
Commercially available	1.72	1.66	1.30
Developed at engine	1.59	1.53	1.20

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.55	Carbon dioxide (CO_2)	12.3
Volatile matter	26.00	Carbon monoxide (CO)	15.0
Fixed carbon	49.88	Hydrogen (H_2)	14.0
Ash	20.57	Methane (CH_4)	.19
Sulphur	.76	Nitrogen (N_2)	56.4
		Ethylene (C_2H_4)	.4

COKING TEST.

Tennessee No. 6 (run of mine).

Test 122.—Size as used: Raw, finely crushed. Duration of test, 43 hours. Coal charged, 12,000 pounds. Coke produced, 7,712 pounds; 64.27 per cent. Breeze produced, 314 pounds; 2.62 per cent. Total yield, 66.89 per cent. Light gray and silvery. Good, heavy, strong coke. Could be improved by washing to reduce ash.

Analyses.

	Coal.	Coke.
Moisture	2.05	0.22
Volatile matter	27.36	.91
Fixed carbon	55.12	79.01
Ash	15.47	19.86
Sulphur	.90	.69

Cupola tests of coke made from Tennessee No. 6 coal.

CHARGE.

Cupola test No.	Coke. [a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
112	122	1.95	7	.....	Coke	230	50	50	50	50	430
					Pig iron	690	390	390	390	390	2,250
					Scrap	230	130	130	130	130	750
141	122	1.95	7	99.9	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750

[a] Sulphur in ash 0.03 per cent. Phosphorus in coke, 0.0834 per cent.

Cupola tests of coke made from Tennessee No. 6 coal—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Mins.*	*Lbs.*	*Lbs.*	*Lbs.*	*Mins.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
112	(a)	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
141	8.05 a. m....	7	5	749	296	1,045	30	2,090	4.48	4.90	1,808	197

a Blast on 30 minutes; no iron melted. Coke very high in ash, and dirty.

LADLE RECORD.

Ladle No.	Test 141.		Ladle No.	Test 141.	
	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).
1	36	8.18	8	57	8.32½
2	78	8.23	9	45	8.33
3	88	8.24	10	55	8.36
4	78	8.28	11	51	8.36½
5	69	8.28½	12	24	8.37
6	40	8.29	13	56	8.39
7	57	8.32	14	15	8.40

Remarks.—Test, 141: Iron cold.

TENNESSEE NO. 7.

Bituminous coal from Wilder, Fentress County, on the Southern Railway, was designated Tennessee No. 7. The coal, as worked from the outcrop at this place, averages 4 feet 4 inches in thickness.

Two samples of coal were shipped from this mine, both inspected by John W. Groves. Tennessee No. 7 A consisted of run-of-mine screened over a ¼-inch by 1-inch shaker screen, and was used in making steaming tests 372, 373, and 374 and producer-gas test 108. Tennessee No. 7 B consisted of slack coal through a plate perforated with ¼-inch by 1-inch holes, and was used in making steaming test 406 (on briquets); washing test 156; coking tests 121 (raw) and 123 (washed); cupola tests 113 and 137; and briquetting test 121.

Two mine samples were taken for chemical analysis. Sample 2979 was taken 2,000 feet north of the drift mouth, where the coal measured 4 feet 7 inches in thickness. Sample 2980 was taken 1,500 feet east of the drift mouth, where the coal measured 4 feet ½ inch in thickness.

CHEMICAL ANALYSES.

Tennessee No. 7.

	Mine samples.		Car sample.[a]	Steaming tests.[b]			
				372.	373.	374.	406.
Laboratory No	2979	2980	3133				
Air-drying loss	2.00	1.80	1.70				
Proximate:							
Moisture	3.46	3.04	3.03	2.98	3.06	3.36	3.37
Volatile matter	34.73	36.37	34.91	34.46	34.30	33.62	35.80
Fixed carbon	52.73	50.46	49.21	49.58	48.49	49.45	50.77
Ash	9.08	10.13	12.85	12.98	14.15	13.57	10.06
Sulphur	2.42	3.84	3.26	3.35	4.18	3.34	2.09
Ultimate:							
Hydrogen			5.03	4.83	4.70	4.79	5.02
Carbon			69.26	71.23	69.47	70.67	75.58
Nitrogen			1.27	1.31	1.27	1.29	1.36
Oxygen			8.33	5.79	5.65	5.75	5.47
Ash				13.39	14.60	14.04	10.41
Sulphur				3.45	4.31	3.46	2.16
Calorific value (as received):							
Determined, calories	7,213		7,001				
Determined, B. t. u.	12,983		12,602				
Calculated from ultimate analysis, calories			7,045				
Calculated from ultimate analysis, B. t. u.			12,681				

[a] Sample from producer-gas test 108 treated as car sample.
[b] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 7.

	A.			B.
	Test 372.	Test 373.[a]	Test 374.	Test 406.
Size as used:				
Over 1 inch ... per cent	51.6	26.1	47.3	See p. 247
½ inch to 1 inch ... do	22.6	37.5	20.4	
¼ inch to ½ inch ... do	12.4	18.5	12.6	
Under ¼ inch ... do	13.4	17.9	19.7	
Duration of test ... hours	9.98	9.93	9.95	6.15
Heating value of fuel ... B. t. u. per pound dry fuel	12,965	12,681	12,866	13,547
Force of draft:				
Under stack damper ... inch water	0.48	0.69	0.49	0.64
Above fire ... do	.15	.23	.15	.17
Furnace temperature ... °F	2,660	2,958	2,461	2,420
Dry fuel used per square foot of grate surface per hour ... pounds	20.94	26.76	18.45	20.91
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.59	4.53	3.26	3.85
Percentage of rated horsepower of boiler developed	100.7	127.1	91.4	108.0
Water apparently evaporated per pound of fuel as fired ... pounds	7.04	6.93	7.22	7.66
Water evaporated from and at 212° F.:				
Per pound of fuel as fired ... do	8.33	8.23	8.56	8.92
Per pound of dry fuel ... do	8.59	8.49	8.86	9.23
Per pound of combustible ... do	10.11	10.06	10.48	10.42
Efficiency of boiler, including grate ... per cent	63.98	64.65	66.50	65.80
Fuel as fired:				
Per indicated horsepower hour ... pounds	3.39	3.44	3.30	3.17
Per electrical horsepower hour ... do	4.19	4.24	4.08	3.91
Dry fuel:				
Per indicated horsepower hour ... do	3.29	3.33	3.19	3.06
Per electrical horsepower hour ... do	4.06	4.11	3.94	3.78

[a] Maximum capacity test.

Remarks.—Test 406 on briquets from test 121. The briquets burned with a long flame, cracked open to a depth of three-fourths of an inch, coked, and held together well until entirely consumed. No smoke; very little clinker; reddish-brown ash.

PRODUCER-GAS TEST.

Tennessee No. 7 A (run of mine).

Test 108.—Duration of test, 50 hours. Average electrical horsepower, 192.5. Average B. t. u. per cubic foot of gas, 154.6. Total coal fired, 14,400 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.60	1.55	1.35
Developed at switchboard	1.50	1.45	1.26
Per brake horsepower:			
Commercially available	1.36	1.32	1.14
Developed at engine	1.27	1.23	1.07
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.74	1.69	1.46
Developed at switchboard	1.63	1.58	1.37
Per brake horsepower:			
Commercially available	1.48	1.43	1.24
Developed at engine	1.38	1.35	1.16

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	11.2
Carbon monoxide (CO)	17.4
Hydrogen (H_2)	15.3
Methane (CH_4)	2.3
Nitrogen (N_2)	53.3
Ethylene (C_2H_4)	.5

WASHING AND COKING TESTS.

Tennessee No. 7 B (slack).

Washing test 156.—Jig used, Stewart. Raw coal, 31,000 pounds; washed coal, 21,000 pounds; refuse, 10,000 pounds.

Coking tests.

		Test 121 (raw).	Test 123 (w.).
Size as used		f.c.	f.c.
Duration of test	hours	46	50
Coal charged	pounds	12,000	12,000
Coke produced	do	6,680	6,911
	per cent	55.67	57.59
Breeze produced	pounds	716	323
	per cent	5.97	2.69
Total yield	do	61.64	60.28

Remarks.—Test 121: Poor coke, soft and punky; coal high in ash and sulphur; might be improved by washing. Test 123: Light gray and silvery, with good ring; great improvement over raw charge; sulphur still too high.

Analyses.

	Washing test 156.		Coking test 121.		Coking test 123.	
	Raw coal.	Washed coal.	Coal.	Coke.	Coal.	Coke.
Moisture	7.88	7.04	7.88	0.43	8.37	0.57
Volatile matter	28.28	.....	28.28	.36	32.29	.87
Fixed carbon	46.43	.....	46.43	74.43	49.02	83.59
Ash	17.41	10.12	17.41	24.78	10.32	14.97
Sulphur	3.43	2.26	3.43	2.98	2.21	1.77

[a] For analyses of fuel used see p. 245 (sample 3133).

Cupola tests of coke made from Tennessee No. 7 B coal (washed).

CHARGE.

Cupola test No.	Coke.[a] Test No.	Coke. Specific gravity.	Coke. Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
113	123	1.93	7	98.61	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
137	123	1.93	7	95.83	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750

[a] Sulphur in ash, 0.04 per cent. Phosphorus in coke, 0.0468 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure. On at—	Blast pressure. Maximum.	Iron running in—	Weight of iron. Poured.	Weight of iron. Additional melted.	Weight of iron. Total.	Melting. Time.	Melting. Rate per hour.	Melting. Ratio iron to coke.	Melting. Loss.	Recovered. Iron.	Recovered. Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
113	3.30 p. m.	7	8	2,384	132	2,516	30	5,032	8.70	12.06	122	141
137	10.30 a. m.	6½	9	1,446	444	1,890	34	3,336	6.26	5.60	942	128

LADLE RECORD.

Ladle No.	Test 113. Pounds.	Test 113. Time (p. m.).	Test 137. Pounds.	Test 137. Time (a. m.).	Ladle No.	Test 113. Pounds.	Test 113. Time (p. m.).	Test 137. Pounds.	Test 137. Time (a. m.).
1	93	3.47	88	10.48	14	105	4.03	63	11.02
2	56	3.47½	96	10.48½	15	87	4.03½	35	11.03
3	102	3.51½	61	10.49	16	94	4.04	86	11.06
4	93	3.52	76	10.53	17	105	4.05	61	11.07
5	78	3.56	88	10.53½	18	88	4.05½	67	11.12
6	102	3.56½	93	10.54	19	90	4.06	84	11.13
7	83	3.57	67	10.55	20	106	4.07	.....	.....
8	71	3.59	70	10.55½	21	83	4.07½	.....	.....
9	106	3.59½	76	10.56½	22	90	4.08	.....	.....
10	97	4.00	97	10.57	23	106	4.08½	.....	.....
11	87	4.01	92	10.58	24	84	4.09	.....	.....
12	110	4.01½	100	10.59½	25	96	4.09½	.....	.....
13	93	4.02	46	11.01	26	79	4.11	.....	.....

Remarks.—Test 113: Iron very hot and fluid. Blast off, 3 minutes. Test 137: Iron cold.

BRIQUETTING TEST.

Tennessee No. 7 B (washed slack).

Test 121.—Size as used: Over ¼ inch, 1.8 per cent; $\frac{1}{10}$ inch to ¼ inch, 10.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 19 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 21 per cent; through $\frac{1}{40}$ inch, 47.4 per cent. Machine used, English. Temperature of briquets, 179.6° F. Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40). Amount of binder, 5.5, 6, 6.5, and 7 per cent. Weight of fuel briquetted, 7,000 pounds; average weight of briquets, 3.08 pounds. B. t. u. per pound of coal as received, 12,447; per pound of briquets as fired, 13,090; per pound of binder, 16,478. Weathering test: Days exposed, 200; condition, B. For analyses of briquets see page 245 (steaming test 406).

Briquets with 5.5 and 6 per cent of binder had firm edges, but surfaces were slightly crumbly when rubbed; broke with a clean fracture, leaving a firm surface; those with 6.5 and 7 per cent of binder had hard and smooth surfaces; fracture hard and firm. Not enough coal was furnished to make tests on Renfrow machine or steaming tests on unbriquetted fuel.

Drop test.

Percentage of binder	5.5	6	6.5	7
Held by 1-inch screen	78.3	79.9	89.5	95.2
Passed 1-inch screen	21.7	20.1	10.5	4.8

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 121.
Laboratory No	3410		
Air-drying loss ... per cent		6.10	1.80
Extracted by CS_2:			
Air-dried ... do		1.96	6.16
As received ... do	79.98	1.84	6.05
Pitch in briquets as received ... do			5.39

TENNESSEE NO. 8.

Bituminous coal from Clifty, White County, on the Nashville, Chattanooga and St. Louis Railway, was designated Tennessee No. 8. The coal, as worked from the outcrop at this place, averages 3 feet 6 inches in thickness.

Two lots of coal were shipped from this mine, both inspected by John W. Groves. Tennessee No. 8 A consisted of "special run of mine," which is made by passing coal over a ¾-inch screen and returning about 8 per cent slack to the sample. Tennessee No. 8 B consisted of "screened run of mine," which was passed over a ¾-inch screen and had about 18 per cent of slack returned to it. These samples were used mixed in making steaming tests 384 (raw), 385 (raw), and 388 (washed); producer-gas tests (washed) 116 and 119; washing test 157; coking test 134 (washed coal), and cupola tests 114 and 135.

Two mine samples were taken for chemical analysis. Sample 3005 was taken 2,100 feet north of the drift mouth, where the coal measured 3 feet ¾ inch in thickness. Sample 3006 was taken 1,900 feet north of the drift mouth, where the coal measured 4 feet in thickness.

CHEMICAL ANALYSES.

Tennessee No. 8.

	Mine samples.		Car samples.		Steaming tests.[a]		
			A.	B.	384.	385.	388.
Laboratory No	3005	3006	3127	3128	.....	.....	.....
Air-drying loss	1.90	2.20	1.60	2.00	.....	.....	.....
Proximate:							
Moisture	3.01	3.23	2.63	3.12	2.40	2.36	2.83
Volatile matter	34.70	32.18	33.51	32.91	32.61	33.60	34.70
Fixed carbon	51.53	53.43	50.44	49.85	50.12	50.72	52.24
Ash	10.76	11.16	13.42	14.12	14.87	13.32	10.23
Sulphur	3.42	3.58	4.38	4.74	5.28	4.32	2.92
Ultimate:							
Hydrogen	.....	.....	4.89	4.68	4.41	4.74	5.00
Carbon	.....	.....	69.32	68.20	69.37	71.37	75.31
Nitrogen	.....	.....	1.15	1.23	1.25	1.19	1.25
Oxygen	.....	.....	6.84	7.03	4.32	4.63	4.91
Ash	.....	.....	.....	.....	15.24	13.64	10.53
Sulphur	.....	.....	.....	.....	5.41	4.43	3.00
Calorific value (as received):							
Determined, calories	7,280	.....	7,064	6,954	.....	.....	.....
Determined, B. t. u.	13,104	.....	12,715	12,517	.....	.....	.....
Calculated from ultimate analysis, calories	.....	.....	7,092	6,927	.....	.....	.....
Calculated from ultimate analysis, B. t. u	.....	.....	12,766	12,469	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 8 (run of mine).

	Test 384.	Test 385.	Test 388 (w.).
Size as used:			
Over 1 inch ..... per cent	36.6	37.0	27.5
½ inch to 1 inch ..... do	28.1	26.1	25.6
¼ inch to ½ inch ..... do	15.8	14.6	19.4
Under ¼ inch ..... do	19.5	22.3	27.5
Duration of test ..... hours	10.02	10.08	10.03
Heating value of coal ..... B. t. u. per pound dry coal	12,758	13,090	13,532
Force of draft:			
Under stack damper ..... inch water	0.58	0.62	0.56
Above fire (natural draft) ..... do	.14	.....	.18
In ash pit (forced draft) ..... do	.....	.25	.....
Furnace temperature ..... ° F.	.....	2,243	2,309
Dry coal used per square foot of grate surface per hour ..... pounds	15.64	18.40	20.47
Equivalent water evaporated per square foot of water-heating surface per hour ..... pounds	2.60	3.08	3.78
Percentage of rated horsepower of boiler developed	72.8	86.5	106.1
Water apparently evaporated per pound of coal as fired ..... pounds	6.87	6.98	7.68
Water evaporated from and at 212° F.:			
Per pound of coal as fired ..... do	8.12	8.20	8.99
Per pound of dry coal ..... do	8.32	8.40	9.26
Per pound of combustible ..... do	10.19	9.94	10.52
Efficiency of boiler, including grate ..... per cent	62.98	61.97	66.08
Coal as fired:			
Per indicated horsepower hour ..... pounds	3.48	3.45	3.15
Per electrical horsepower hour ..... do	4.30	4.26	3.88
Dry coal:			
Per indicated horsepower hour ..... do	3.40	3.37	3.05
Per electrical horsepower hour ..... do	4.20	4.16	3.77

PRODUCER-GAS TESTS.

Tennessee No. 8, washed (run of mine).

	Test 116.	Test 119.
Duration of test ..... hours	50	24
Average electrical horsepower	147.4	197.0
Average B. t. u. per cubic foot of gas	144.6	157.5
Total coal fired ..... pounds	11,250	6,550

PRODUCER-GAS TESTS—Continued.

Tennessee No. 8, washed (run of mine).

	Test 116.[a]			Test 119.*		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).						
Per electrical horsepower:						
Commercially available				1.48	1.44	1.30
Developed at switchboard	1.56	1.53	1.37	1.39	1.35	1.22
Per brake horsepower:						
Commercially available				1.26	1.23	1.10
Developed at engine	1.32	1.30	1.16	1.18	1.15	1.03
Equivalent used by producer plant (pounds).						
Per electrical horsepower:						
Commercially available				1.58	1.54	1.39
Developed at switchboard	1.69	1.66	1.48	1.48	1.41	1.30
Per brake horsepower:						
Commercially available				1.34	1.31	1.18
Developed at engine	1.43	1.41	1.26	1.26	1.23	1.10

[a] Without tar extractor.

Analyses.

	Test 116.	Test 119.		Test 116.	Test 119.
Coal.			*Gas by volume.*		
Moisture	1.62	2.43	Carbon dioxide (CO_2)	9.9	9.7
Volatile matter	34.44	35.41	Carbon monoxide (CO)	19.7	19.1
Fixed carbon	53.32	52.29	Hydrogen (H_2)	14.3	15.1
Ash	10.62	9.87	Methane (CH_4)	1.9	2.1
Sulphur	3.05	3.06	Nitrogen (H_2)	53.8	53.5
			Ethylene (C_2H_4)	.4	.5

WASHING AND COKING TESTS.

Tennessee No. 8 (run of mine).

Washing test 157.—Size as used, crushed to 2 inches; jig used, Stewart. Raw coal, 98,000 pounds; washed coal, 86,000 pounds; refuse, 12,000 pounds.

Coking test 134.—Size as used, washed, finely crushed. Duration of test, 45 hours. Coal charged, 12,000 pounds. Coke produced, 6,870 pounds, 57.25 per cent. Breeze produced, 320 pounds, 2.67 per cent. Total yield, 59.92 per cent. Light gray and silvery. Good coke physically, but washing does not reduce sulphur sufficiently.

Analyses.

	Washing test 157.		Coking test 134.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	3.12	1.71	3.09	0.32
Volatile matter	32.91	.....	35.32	.11
Fixed carbon	49.85	.....	51.70	85.66
Ash	14.12	9.99	9.89	13.91
Sulphur	4.74	2.94	2.95	2.45

Cupola tests of coke made from Tennessee No. 8 coal (washed).

CHARGE.

Cupola test No.	Coke.[a] Test No.	Coke. Specific gravity.	Coke. Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
114	134	1.98	7	93.14	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
135	134	1.98	7	97.22	Coke	180	63	63	62	62	430
					Pig iron	540	428	428	427	427	2,250
					Scrap	180	143	143	142	142	750

[a] Phosphorus in coke, 0.0238 per cent.

RECORD OF MELT.

Cupola test No.	Blast pressure. On at—	Blast pressure. Maximum.	Iron running in—	Weight of iron. Poured.	Weight of iron. Additional melted.	Weight of iron. Total.	Melting. Time.	Melting. Rate per hour.	Melting. Ratio iron to coke.	Melting. Loss.	Recovered. Iron.	Recovered. Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
114	11.05 a. m.	7	7	2,301	217	2,518	36	3,918	6.92	8.36	231	66
135	9.47 a. m.	7	7	1,547	1,034	2,581	27	5,956	6.59	8.33	169	38

LADLE RECORD.

Ladle No.	Test 114. Pounds.	Test 114. Time (a. m.).	Test 135. Pounds.	Test 135. Time (a. m.).	Ladle No.	Test 114. Pounds.	Test 114. Time (a. m.).	Test 135. Pounds.	Test 135. Time (a. m.).
1	61	11.18	30	9.56	15	95	11.34	73	10.14
2	92	11.24	72	9.58	16	64	11.34½	74	10.15
3	105	11.24½	102	10.00	17	78	11.36	82	10.17
4	64	11.25	75	10.01	18	103	11.36½	107	10.17½
5	74	11.27	87	10.04	19	96	11.37	76	10.18
6	98	11.27½	87	10.04½	20	77	11.37½	111	10.21
7	87	11.28	84	10.06½	21	92	11.38½	.....	.....
8	78	11.28½	78	10.07	22	74	11.39	.....	.....
9	61	11.30	21	10.07½	23	83	11.39½	.....	.....
10	83	11.30½	89	10 09	24	104	11.40	.....	.....
11	101	11.31	80	10.11½	25	57	11.46½	.....	.....
12	109	11.31½	85	10.12	26	67	11.47	.....	.....
13	104	11.33	65	10.12½	27	104	11.48	.....	.....
14	90	11.33½	69	10.13½					

Remarks.—Test 114: Iron very hot. Test 135: Iron hot. Blast off 1 minute; top hole cut out and iron run over trough.

TENNESSEE NO. 9.

Bituminous coal from Coalmont, Grundy County, on the Nashville, Chattanooga and St. Louis Railway, was designated Tennessee No. 9. The coal, as worked from the outcrop at this place, averages 3 feet 4 inches in thickness.

One car of coal was shipped from this mine under the supervision of John W. Groves. Twenty tons of lump, over a ¾-inch screen, designated A, was used in making steaming tests 363, 364, and 365.

Ten tons of slack, designated B, was used in making washing test 158; and this coal, washed, in addition to 14 tons of slack, designated C, as shipped, was used in making steaming test (on briquets) 393; also in coking test 124, cupola tests 110 and 136, and briquetting test 122.

Two mine samples were taken for chemical analysis. Sample 2995 was taken 1,900 feet north of the drift mouth, where the coal measured 3 feet in thickness. Sample 2996 was taken 2,000 feet south of the drift mouth, where the coal measured 3 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 9.

	Mine samples.		Car samples.			Steaming tests.[a]			
						A.			B and C
			A.	B.	C.	363.	364.	365.	393.
Laboratory No	2995	2996	3113	3114	3115				
Air-drying loss	2.30	2.40	2.60	4.70	3.30				
Proximate:									
Moisture	3.44	3.77	3.92	5.68	4.68	4.46	3.48	3.60	4.24
Volatile matter	29.24	28.60	27.23	25.36	28.75	27.36	27.86	28.40	29.80
Fixed carbon	58.11	59.46	54.76	50.41	57.31	55.70	56.34	53.26	56.10
Ash	9.21	8.17	14.09	18.55	9.26	12.48	12.32	14.74	9.86
Sulphur	.73	.68	.94	.74	.65	1.01	.79	.78	.79
Ultimate:									
Hydrogen			4.81	5.02	5.04	4.63	4.66	4.52	4.60
Carbon			69.97	64.58	73.85	74.13	74.62	72.43	77.00
Nitrogen			1.29	1.20	1.24	1.37	1.38	1.34	1.43
Oxygen			8.90	9.91	9.96	5.75	5.76	5.61	5.84
Ash						13.06	12.76	15.29	10.30
Sulphur						1.06	.82	.81	.83
Calorific value (as received):									
Determined, calories	7,344		6,949	6,378	7,313				
Determined, B. t. u.	13,219		12,508	11,480	13,163				
Calculated from ultimate analysis, calories			6,950	6,537	7,288				
Calculated from ultimate analysis, B. t. u.			12,510	11,767	13,118				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 9.

	A.			B and C.
	Test 363.	Test 364.	Test 365.	Test 393.
Size as shipped	¾-in. l.	¾-in. l.	¾-in. l.	
Size as used:				
Over 1 inch, percent	12.6	13.8	7.1	See p. 254
½ inch to 1 inch, do	24.5	22.4	17.3	
¼ inch to ½ inch, do	24.5	23.8	22.8	
Under ¼ inch, do	38.4	40.0	52.8	
Duration of test, hours	10.0	9.95	9.98	10.13
Heating value of fuel, B. t. u. per pound dry coal	13,257	13,333	12,938	13,613
Force of draft:				
Under stack damper, inch water	0.65	0.70	0.71	0.62
Above fire, do	.15	.19	.24	.23
Furnace temperature, °F.	2,263	2,296	2,284	2,276
Dry fuel used per square foot of grate surface per hour, pounds	19.80	21.90	21.01	21.60
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.51	3.81	3.52	4.07
Percentage of rated horsepower of boiler developed	98.5	106.9	98.8	114.0
Water apparently evaporated per pound of fuel as fired, pounds	7.21	7.20	6.92	7.71
Water evaporated from and at 212° F.:				
Per pound of fuel as fired, pounds	8.50	8.41	8.10	9.03
Per pound of dry fuel, do	8.89	8.71	8.40	9.43
Per pound of combustible, do	10.47	10.15	10.16	10.62

STEAMING TESTS—Continued.

Tennessee No. 9.

	A.			B and C.
	Test 363.	Test 364.	Test 365.	Test 393.
Efficiency of boiler, including grate.....per cent..	64.76	63.09	62.70	66.90
Fuel as fired:				
Per indicated horsepower hour.....pounds..	3.33	3.36	3.49	3.13
Per electrical horsepower hour.....do....	4.11	4.15	4.31	3.87
Dry fuel:				
Per indicated horsepower hour.....do....	3.18	3.25	3.37	3.00
Per electrical horsepower hour.....do....	3.93	4.01	4.16	3.70

Remarks.—Test 393 on briquets, which were very firm and burned freely, with long flame and without smoke. They swelled in the fire and then fell to pieces. Nearly all of the briquets were fired whole. Clinker solid, heavy and brittle, and of a light-brown color.

WASHING AND COKING TESTS.

Tennessee No. 9.

Washing test 158 (*coal B, slack*).—Jig used, Stewart. Raw coal, 19,385 pounds; washed coal, 14,420 pounds; refuse, 4,965 pounds.

Coking test 124 (*coals B and C, slack*).—Size as used: Finely crushed. Duration of test, 49 hours. Coal charged, 12,000 pounds. Coke produced, 7,948 pounds; 66.23 per cent. Breeze produced, 283 pounds; 2.36 per cent. Total yield, 68.59 per cent. Light gray with some little deposit of carbon. Good coke.

Analyses.

	Washing test 158.		Coking test 124.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	5.68	4.02	4.02	0.39
Volatile matter	25.36	27.79	27.79	.39
Fixed carbon	50.41	58.28	58.28	85.78
Ash	18.55	9.91	9.91	13.44
Sulphur	.74	.85	.85	.61

Cupola tests of coke made from Tennessee Nos. 9 B and 9 C coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
110	124	1.93	7	99.9	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
136	124	1.93	7	93.05	Coke	200	58	58	57	57	430
					Pig iron	600	413	413	412	412	2,250
					Scrap	200	138	138	137	137	750

[a] Sulphur in ash, 0.04 per cent. Phosphorus in coke, 0.0968 per cent.

Cupola tests of coke made from Tennessee Nos. 9 B and 9 C coal (washed)—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
110	3.27 p. m.	6½	6	1,950	110	2,060	34	3,635	6.28	6.83	735	102
136	3.41 p. m.	7	7	2,106	250	2,356	26	5,437	6.83	1.13	615	85

LADLE RECORD.

Ladle No.	Test 110.		Test 136.		Ladle No.	Test 110.		Test 136.	
	Pounds.	Time (p. m.).	Pounds.	Time (p. m.).		Pounds.	Time (p. m.).	Pounds.	Time (p. m.).
1	46	3.37	96	3.57	13	97	3.54	107	4.06½
2	86	3.42	110	3.57½	14	87	3.57½	88	4.07
3	103	3.42½	43	3.58	15	100	3.58	84	4.07½
4	24	3.43	77	3.59	16	105	3.59	100	4.09
5	95	3.45½	103	4.00	17	88	4.01	93	4.09½
6	100	3.46	111	4.00½	18	98	4.02	84	4.10
7	101	3.47	30	4.01	19	93	4.02½	91	4.10½
8	94	3.49	88	4.01½	20	86	4.05½	109	4.11
9	103	3.49½	101	4.03	21	91	4.06	92	4.11½
10	55	3.50	104	4.03½	22	98	4.07	108	4.13
11	96	3.53	72	4.04	23	.....	.....	57	4.13½
12	104	3.53½	93	4.06	24	.....	.....	65	4.14

Remarks.—Test 110: Iron very hot and fluid.

BRIQUETTING TEST.

Tennessee Nos. 9 B and 9 C (washed slack).

Test 122.—Size as used: Over ¼ inch, 1.2 per cent; $\frac{1}{10}$ inch to ¼ inch, 5.5 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 12.5 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 23.8 per cent; through $\frac{1}{40}$ inch, 57 per cent. Machine used, English. Temperature of briquets, 179.6° F. Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40). Weight of fuel briquetted, 14,400 pounds; average weight of briquets, 3.24 pounds. B. t. u. per pound of coal as received, 13,163; per pound of briquets as fired, 13,047; per pound of binder, 16,478. For analyses of briquets see page 252 (steaming test 393).

With 5.4 and 5.6 per cent binder, briquets were fairly good, but somewhat crumbly at edges. With 6.6, 7, and 8 per cent binder, outer surfaces were very firm and smooth, fracture coarse, but not crumbly; broken surfaces very hard. In drop test, with 7 per cent binder, the 1-inch screen held 85.6 per cent and passed 14.4 per cent. Weathering test: All binders exposed 222 days; condition, B. Not enough coal was furnished to make briquets on Renfrow machine for comparative tests.

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 122.
Laboratory No.	3410	3338	.....
Air-drying loss ... per cent	.....	4.7	2.5
Extracted by CS_2:			
Air-dried ... do	.....	.2	5.45
As received ... do	79.98	.19	5.31
Pitch in briquets as received ... do	.....	.....	6.41

TENNESSEE NO. 10.

Bituminous coal from a mine located 1 mile north of Orme, Marion County, on the Nashville, Chattanooga and St. Louis Railway, was designated Tennessee No. 10. This coal, as worked from the outcrop at this place, averages 5 feet 8 inches in thickness.

This sample, consisting of slack coal shipped under the supervision of W. J. Von Borries, was used in making steaming tests (on briquets) 407 and 408, washing test 173, coking test 156, cupola tests 111 and 127, and briquetting test 128.

Two mine samples were taken for chemical analysis. Sample 3009 was taken 2,200 feet northeast of the opening, where the coal measured 5 feet 8 inches in thickness. Sample 3010 was taken 2,500 feet northwest of the opening, where the coal measured 5 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Tennessee No. 10.

	Mine samples.		Steaming tests.[a]	
			407.	408.
Laboratory No	3009	3010	.....	.....
Air-drying loss	2.00	2.00	.....	.....
Proximate:				
Moisture	3.31	3.37	2.46	2.88
Volatile matter	31.71	32.38	30.89	30.84
Fixed carbon	51.87	53.13	51.80	49.55
Ash	13.11	11.12	14.85	16.73
Sulphur	1.30	.65	1.02	.96
Ultimate:				
Hydrogen	.....	.....	4.47	4.56
Carbon	.....	.....	71.53	69.82
Nitrogen	.....	.....	1.30	.92
Oxygen	.....	.....	6.43	6.48
Ash	.....	.....	15.22	17.23
Sulphur	.....	.....	1.05	.99
Calorific value determined (as received) calories	6,774	.....	.....	.....
Calorific value determined (as received) B. t. u.	12,193	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Tennessee No. 10 (washed briquets).

	Test 407.	Test 408.
Duration of test ... hours	4.72	3.87
Heating value of fuel ... B. t. u. per pound dry fuel	12,667	12,272
Force of draft:		
Under stack damper ... inch water	0.68	0.68
Above fire ... do	.18	.15
Furnace temperature ... °F	[a]1,184	2,226
Dry fuel used per square foot of grate surface per hour ... pounds	18.05	19.28
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	2.80	3.32
Percentage of rated horsepower of boiler developed	78.6	93.1
Water apparently evaporated per pound of fuel as fired ... pounds	6.53	7.21
Water evaporated from and at 212° F.:		
Per pound of fuel as fired ... do	7.58	8.38
Per pound of dry fuel ... do	7.77	8.63
Per pound of combustible ... do	9.42	10.83
Efficiency of boiler, including grate ... per cent	59.24	67.91
Fuel as fired:		
Per indicated horsepower hour ... pounds	3.73	3.37
Per electrical horsepower hour ... do	4.61	4.17
Dry fuel:		
Per indicated horsepower hour ... do	3.64	3.28
Per electrical horsepower hour ... do	4.49	4.05

[a] Average is not representative of test. In one-third of the observations the temperature was too low to be read by Wanner *optical pyrometer*.

Remarks.—Tests made on English briquets, which were broken in two before firing. They cracked open to a depth of 1½ inches, but coked and kept their shape until entirely consumed. No smoke. Ash and clinker were brown.

WASHING AND COKING TESTS.

Tennessee No. 10 (1-inch slack).

Washing test 173.—Jig used, Stewart. Raw coal, 60,500 pounds; washed coal, 47,400 pounds; refuse, 13,100 pounds.

Coking test 156.—Size as used: Washed, finely crushed. Duration of test, 53 hours. Coal charged, 11,690 pounds. Coke produced, 6,900 pounds; 59.02 per cent. Breeze produced, 757 pounds; 6.48 per cent. Total yield, 65.50 per cent. Poor coke; soft and dense; heavy black butt; practically no cell structure; high ash.

Analyses.

	Washing test 173.		Coking test 156.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	2.92	7.02	7.80	1.67
Volatile matter	.....	.....	29.29	.81
Fixed carbon	.....	.....	49.32	77.81
Ash	22.74	3.75	13.59	19.71
Sulphur	.95	.98	1.05	.95

Cupola tests of coke made from Tennessee No. 10 coal (washed).

CHARGE.

Cupola test No.	Coke.[a]			Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.		1.	2.	3.	4.	5.	
					Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
111	156	1.90	7	Coke	230	50	50	50	50	430
				Pig iron	690	390	390	390	390	2,250
				Scrap	230	130	130	130	130	750
127	156	1.90	.....	Coke	250	.....	.....	.....	.....	.....

[a] Phosphorus in coke, 0.0390 per cent.

Remarks.—Test 111: Blast on from 10.51 a. m. for 30 minutes, at maximum pressure of 7 ounces; no iron melted. Test 127: Coke bed put in and blast put on for 20 minutes; coke would not ignite; bottom dropped without charging iron.

BRIQUETTING TEST.

Tennessee No. 10 (1-inch slack, washed).

Test 128.—Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40). Weight of fuel briquetted, 35,400 pounds. B. t. u. per pound of coal from car sample, 11,596; per pound of briquets as fired, 11,920; per pound of binder, 16,478. The briquets made with the three percentages of pitch (5.5, 6.5, and 6.7) were all good.

English briquets made at 175° F., average weight 3.63 pounds, with 5.5 per cent binder, could be roughened slightly by rubbing; outer surfaces crumbled slightly when broken. Briquets with 6 and 6.5 per cent binder could be roughened slightly by rubbing; outer surfaces hard and smooth; broken surfaces very hard and rough. In the drop test of English briquets with 5.5 per cent binder the 1-inch screen held 81.7 per cent and passed 18.3 per cent; with 6 per cent binder the screen held 90.1

per cent and passed 9.9 per cent; with 6.5 per cent binder the screen held 89.1 per cent and passed 10.9 per cent. In the weathering test all briquets were exposed 203 days, condition B. For analyses of briquets see page 255 (steaming tests 407 and 408).

Renfrow briquets made at 149° F., average weight 0.53 pound, with 6 per cent binder, showed crumbly, fractured surfaces. With 6.5 per cent binder briquets were tougher and did not break as easily, and broken surfaces were firm, but still appeared short on pitch. In the weathering test briquets with both binders were exposed 204 days; condition B.

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 128.
Laboratory No	3410	3359	.....
Air-drying loss ... per cent	.....	5.20	1.3
Extracted by CS_2:			
Air-dried ... do	.....	1.39	7.07
As received ... do	79.98	1.32	6.98
Pitch in briquets as received ... do	.....	.....	7.19

TENNESSEE NO. 11.

Bituminous coal from Ozone, Cumberland County, on the Tennessee Central Railway was designated Tennessee No. 11.

This sample consisted of slack coal through 1¼-inch bar screen. It was shipped without inspection, as additional samples of the run-of-mine coal are to be obtained later when an inspector will be sent to the mine and mine samples taken. The following tests were made on this coal: Washing test 178, coking test 160 (washed coal), and cupola tests 144 and 179.

CHEMICAL ANALYSES.

Tennessee No. 11.

	Car sample.			Car sample.
Laboratory No	3471	Ultimate:		
Air-drying loss	2.30	Hydrogen		4.13
Proximate:		Carbon		59.07
Moisture	3.53	Nitrogen		1.10
Volatile matter	20.75	Oxygen		6.83
Fixed carbon	47.85	Calorific value (as received):		
Ash	27.87	Determined	calories	5,702
Sulphur	.90		B. t. u.	10,264
		Calculated from ultimate analysis	calories	5,931
			B. t. u.	10,676

WASHING AND COKING TESTS.

Tennessee No. 11 (slack).

Washing test 178.—Jig used, Stewart. Raw coal, 42,000 pounds; washed coal, 27,500 pounds; refuse, 14,500 pounds.

Coking test 160.—Size as used: Washed, finely crushed. Duration of test, 40 hours; coal charged, 11,890 pounds; coke produced, 7,650 pounds; 64.34 per cent. Breeze

produced, 550 pounds; 4.63 per cent. Total yield 68.97 per cent. Poor, dense coke; ash very high.

Analyses.

	Washing test 178.		Coking test 160.	
	Raw coal.	Washed coal.	Coal.	Coke.
Moisture	3.53	5.60	5.29	1.14
Volatile matter	20.75	.....	23.61	1.60
Fixed carbon	47.85	.....	56.58	80.14
Ash	27.87	13.47	14.52	17.12
Sulphur	.90	.92	.86	.69

Cupola tests of coke made from Tennessee No. 11 coal (washed).

CHARGE.

Cupola test No.	Coke.			Fluidity strip full.	Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.			1.	2.	3.	4.	5.	
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
144	160	1.97	7	.....	Coke	240	48	48	47	47	430
					Pig iron	960	510	510	510	510	3,000
179	160	1.97	7	86.11	Coke	220	53	53	52	52	430
					Pig iron	660	398	398	397	397	2,250
					Scrap	220	133	133	132	132	750

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke.	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
144	10.50 a. m.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
179	11.28 a. m.	6	16	424	317	741	20	2,223	2.58	2.03	2,189	143

LADLE RECORD.

Ladle No.	Test 179.		Ladle No.	Test 179.	
	Pounds.	Time (a. m.).		Pounds.	Time (a. m.).
1	84	11.51	4	92	11.57
2	41	11.52	5	55	12.03
3	75	11.56	6	77	12.04

Remarks.—Test 144. Blast on 32 minutes; no iron melted; all pig iron used to determine effect of sulphur. Test 179: Iron cold and sluggish.

TEXAS.

TEXAS NO. 3.

Lignite from Olsen, Milan County, on the International and Great Northern Railroad, was designated Texas No. 3. The lignite, as worked at a depth of 63 feet at this place, averages 6 feet 6 inches in thickness.

This sample was shipped under the supervision of W. J. Von Borries. It consisted of lump lignite over a ¾-inch screen and was used in making producer-gas test 93.

Two mine samples were taken for chemical analysis. Sample 2562 was taken 400 feet east of the shaft where the coal measured 6 feet 5 inches in thickness. Sample 2563 was taken 500 feet east of the shaft, where the coal measured 6 feet 7 inches in thickness.

CHEMICAL ANALYSES.

Texas No. 3.

	Mine samples.		Car sample.			Mine samples.		Car sample.
Laboratory No.	2562	2563	2734	Ultimate—Continued.				
Air-drying loss	29.10	29.00	23.50	Nitrogen				0.90
Proximate:				Oxygen				39.00
Moisture	36.01	35.56	31.06	Calorific value (as received):				
Volatile matter	27.95	28.91	27.67	Determined	calories	3,962		4,372
Fixed carbon	28.66	27.49	33.39		B. t. u.	7,132		7,870
Ash	7.38	8.04	7.88	Calculated from ultimate analysis	calories			4,203
Sulphur	.77	.75	.99		B. t. u.			7,565
Ultimate:								
Hydrogen			6.53					
Carbon			44.70					

PRODUCER-GAS TEST.

Texas No. 3 (lump).

Test 93.—Size as used: Over 1 inch, 61 per cent; ½ inch to 1 inch, 18 per cent; ¼ inch to ½ inch, 8 per cent; under ¼ inch, 13 per cent. Duration of test, 50 hours. Average electrical horsepower, 200.1. Average B. t. u. per cubic foot of gas, 171.8. Total coal fired, 25,500 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.70	1.83	1.59
Developed at switchboard	2.55	1.73	1.50
Per brake horsepower:			
Commercially available	2.29	1.55	1.35
Developed at engine	2.17	1.47	1.28
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.90	1.97	1.71
Developed at switchboard	2.75	1.86	1.62
Per brake horsepower:			
Commercially available	2.47	1.67	1.46
Developed at engine	2.33	1.58	1.38

Analyses.

Coal.		*Gas by volume.*	
Moisture	32.20	Carbon dioxide (CO_2)	10.3
Volatile matter	30.11	Carbon monoxide (CO)	19.8
Fixed carbon	28.82	Hydrogen (H_2)	14.8
Ash	8.87	Methane (CH_4)	2.4
Sulphur	0.88	Nitrogen (N_2)	51.3
		Oxygen (O_2)	[illegible]
		Ethylene (C_2H_4)	[illegible]

TEXAS NO. 4.

Lignite from Hoyt, Wood County, on the Missouri, Kansas and Texas Railway was designated Texas No. 4. The coal, as worked at a depth of 45 feet at this place, averages 7 feet in thickness.

This sample was shipped under the supervision of W. J. Von Borries. It consisted of run-of-mine coal and was used in making steaming tests 291, 298, and 303; producer-gas test 92, and briquetting test 112.

Two mine samples were taken for chemical analysis. Sample 2635 was taken 1,100 feet southeast of the slope, where the coal measured 6 feet 6 inches in thickness. Sample 2636 was taken 400 feet north of the slope, where the coal measured 8 feet in thickness.

CHEMICAL ANALYSES.

Texas No. 4.

	Mine samples.		Car sample.	Steaming tests.[a]		
				291.	298.	303.
Laboratory No.	2635	2636	2717			
Air-drying loss	29.90	28.40	26.70			
Proximate:						
Moisture	36.80	34.87	33.85	36.27	36.30	33.43
Volatile matter	28.86	29.80	27.50	30.58	30.61	37.80
Fixed carbon	28.09	27.69	31.35	25.14	24.90	18.17
Ash	6.25	7.64	7.30	8.01	8.19	10.60
Sulphur	.53	.50	.51	.51	.50	.68
Ultimate:						
Hydrogen			6.68	4.33	4.32	4.31
Carbon			43.12	64.02	63.83	63.72
Nitrogen			.71	1.05	1.05	1.05
Oxygen			41.68	17.23	17.15	17.14
Ash				12.57	12.86	12.95
Sulphur				.80	.79	.83
Calorific value (as received):						
Determined, calories	3,945		4,165			
Determined, B. t. u.	7,101		7,497			
Calculated from ultimate analysis, calories			4,002			
Calculated from ultimate analysis, B. t. u.			7,204			

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Texas No. 4 (run of mine).

	Test 291.	Test 298.	Test 303.
Size as used:			
Over 1 inch, per cent		44.2	14.7
½ inch to 1 inch, do.		21.7	15.2
¼ inch to ½ inch, do.		14.0	14.7
Under ¼ inch, do.		20.1	55.4
Duration of test, hours	10.18	7.15	[a] 4.32
Kind of grate		Rocking.	Rocking.
Heating value of coal, B. t. u. per pound dry coal	11,131	11,099	11,077
Force of draft:			
Under stack damper, inch water	0.70	0.61	0.65
Above fire, do.		.19	(b)
In ash pit, do.	.49		
Furnace temperature, °F.	2,119	2,269	2,299
Dry coal used per square foot of grate surface per hour, pounds	23.06	35.22	34.15
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.18	3.71	3.44
Percentage of rated horsepower of boiler developed	89.1	104.1	96.4
Water apparently evaporated per pound of coal as fired, pounds	3.68	3.11	3.81

[a] Too short for reliable results. [b] Forced draft.

STEAMING TESTS—Continued.

Texas No. 4 (run of mine).

	Test 291.	Test 298.	Test 303.
Water evaporated from and at 212° F.:			
Per pound of coal as fired ... do	4.40	3.75	4.60
Per pound of dry coal ... do	6.90	5.88	5.62
Per pound of combustible ... do	8.09	6.86	6.99
Efficiency of boiler, including grate ... per cent	59.86	51.16	49.00
Coal as fired:			
Per indicated horsepower hour ... pounds	6.43	7.54	6.15
Per electrical horsepower hour ... do	7.94	9.32	7.59
Dry coal:			
Per indicated horsepower hour ... do	4.10	4.81	5.03
Per electrical horsepower hour ... do	5.06	5.94	6.22

PRODUCER-GAS TEST.

Texas No. 4 (run of mine).

Test 92.—Size as used: Over 1 inch, 68 per cent; ½ inch to 1 inch, 16 per cent; ¼ inch to ½ inch, 7 per cent; under ¼ inch, 9 per cent. Duration of test, 50 hours. Average electrical horsepower, 193.4; average B. t. u. per cubic foot of gas, 156.1; total coal fired, 24,550 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.66	1.75	1.55
Developed at switchboard	2.54	1.67	1.48
Per brake horsepower:			
Commercially available	2.26	1.49	1.32
Developed at engine	2.16	1.42	1.26
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.87	1.89	1.67
Developed at switchboard	2.74	1.81	1.60
Per brake horsepower:			
Commercially available	2.43	1.61	1.42
Developed at engine	2.33	1.54	1.36

Analyses.

Coal.		*Gas by volume.*	
Moisture	34.08	Carbon dioxide (CO_2)	10.3
Volatile matter	33.15	Carbon monoxide (CO)	20.0
Fixed carbon	25.32	Hydrogen (H_2)	15.4
Ash	7.45	Methane (CH_4)	2.5
Sulphur	.49	Nitrogen (N_2)	51.8

BRIQUETTING TEST.

Texas No. 4.

Test 112.—Machine used, English. Temperature of briquets, 179.6° F. Kind of binder, coal-tar pitch; laboratory No. 2933 (see p. 40). Amount of binder, 5, 6, 7, and 8 per cent. Weight of fuel briquetted, 4,500 pounds. B. t. u. per pound of fuel as received, 11,333; per pound of binder, 15,937.

Briquets were of a brown color and full of cracks. The different percentages of binder had no relative effect on the firmness; all fell apart when the pitch hardened. None was satisfactory; did not burn well. They did not swell nor crack, but gradually disintegrated in the fire, burning slowly with characteristic lignite sparking. In the weathering test all briquets were exposed 75 days; condition D.

UTAH.

UTAH NO. 1.

Bituminous coal from prospect on Huntington Creek, Carbon County, was designated Utah No. 1.

Run-of-mine coal was shipped with considerable difficulty and without inspection from this prospect to the testing plant. It was furnished principally for coking tests and no mine samples were taken. The coal was used in making producer-gas test 118, coking test 130, cupola test 118, and briquetting test 126; also mixed with Rhode Island No. 1 in steaming tests (on briquets) 414 and 415 (see p. 223), coking tests 141 and 157, and briquetting test 127.

CHEMICAL ANALYSES.

Utah No. 1.

	Car sample.			Car sample.
Laboratory No.	3199	Ultimate:		
Air-drying loss	3.80	Hydrogen		5.76
Proximate:		Carbon		72.32
Moisture	6.05	Nitrogen		1.38
Volatile matter	42.02	Oxygen		15.12
Fixed carbon	47.06	Calorific value (as received):		
Ash	4.87	Determined	calories	7,306
Sulphur	.55		B. t. u	13,151
		Calculated from ultimate analysis	calories	7,189
			B. t. u	12,940

PRODUCER-GAS TEST.

Utah No. 1 (run of mine).

Test 118.—Duration of test, 50 hours. Average electrical horsepower, 206.2. Average B. t. u. gas per cubic foot, 171.4. Total coal fired, 14,250 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.46	1.38	1.31
Developed at switchboard	1.38	1.30	1.24
Per brake horsepower:			
Commercially available	1.24	1.17	1.11
Developed at engine	1.17	1.11	1.05

Analyses.

Coal.		*Gas by volume.*	
Moisture	5.83	Carbon dioxide (CO_2)	8.5
Volatile matter	42.46	Carbon monoxide (CO)	22.2
Fixed carbon	47.05	Hydrogen (H_2)	15.7
Ash	4.66	Methane (CH_4)	2.6
Sulphur	.57	Nitrogen (N_2)	50.5
		Ethylene (C_2H_4)	.5

COKING TESTS.

Utah No. 1 (run of mine).

		Test 130.	Test 141.	Test 157.
Size as used		f. c.	f. c.	f. c.
Duration of test	hours	49	60	48
Coal charged	pounds	11,810	12,000	12,000
Coke produced	do	5,550	None.	3,504
	per cent	46.99	.....	29.20
Breeze produced	pounds	1,418	.....	3,208
	per cent	12.01	.....	26.73
Total yield	do	59.00	.....	55.93

Remarks.—Test 130: Dull-gray color; very finely fingered, with practically no cell structure. Test 141: Attempt was made to improve coke from Utah No. 1 by lowering volatile of Utah No. 1 by addition of one-third Rhode Island No. 1 (graphitic), but with no success. Test 157: Mixed with one-fourth Rhode Island No. 1; coke very poor; half did not stick together; other half very poor and finely fingered, as in test 130.

Analyses.

	Test 130.		Coal. test 141.	Test 157.	
	Coal.	Coke.		Coal.	Coke.
Moisture	5.83	2.53	4.08	4.60	1.50
Volatile matter	41.89	1.37	28.43	35.38	1.38
Fixed carbon	47.44	88.06	57.52	53.07	86.07
Ash	4.84	8.04	9.97	6.95	11.05
Sulphur	.56	.64	.45	.46	.57

Cupola test of coke made from Utah No. 1 coal.

CHARGE.

Cupola test No.	Coke.[a]			Materials.	Divisions of charge.					Total.
	Test No.	Specific gravity.	Ratio iron to coke.		1.	2.	3.	4.	5.	
					Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
118	130	1.78	7	Coke	200	58	58	57	57	430
				Pig iron	600	413	413	412	412	2,250
				Scrap	200	138	138	137	137	750

[a] Phosphorus in coke, 0.005 per cent.

Remarks.—Blast on at 10.41 a. m. for 20 minutes at maximum pressure of 7 ounces; no iron melted; bed burned out.

BRIQUETTING TESTS.

Utah No. 1 (run of mine).

Test 126.—Size as used: Over ¼ inch, 1.4 per cent; $\frac{1}{16}$ inch to ¼ inch, 5.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 14.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 25 per cent; through $\frac{1}{40}$ inch, 53 per cent. This coal was briquetted with low percentages of binder, with the idea of utilizing the natural resin (probably copalite) contained in the coal. With 4 and 5 per cent binder the heat in the machine would not melt the natural resin, and the briquets were very short on binder and crumbled badly. With 6 per cent binder the surfaces of whole briquets and of fracture crumbled. The use of a still higher per-

centage of pitch would improve the briquets. No drop tests were made on these briquets and no other regular data were obtained, on account of the small amount of the sample.

Test 127 (with Rhode Island No. 1).—Size as used: Over ¼ inch, 1 per cent; $\frac{1}{16}$ inch to ¼ inch, 5.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 9.4 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 26.4 per cent; through $\frac{1}{40}$ inch, 57.4 per cent. This test was made to prove the value of briquetting a good fuel with one that is commercially worthless. A high volatile coal low in ash was chosen to mix with the graphitic coal. Various percentages were tried, but 47 per cent of each coal and 6 per cent binder made an entirely satisfactory briquet. Six per cent binder made excellent briquets; outer surface smooth and polished, and very hard; briquets broke without crumbling, and broken surfaces were smooth and hard. For analyses of briquets see page 223 (steaming tests 414 and 415).

	Test 126.	Test 127.		Test 126.	Test 127.
Details of manufacture:			Details of manufacture—Continued.		
Machine used	Renf.	Renf.	Heat value per pound—		
Temperature of briquets, ° F	149	149	Fuel as received, B. t. u.	13,151	12,259
Binder—			Fuel as fired, B. t. u.	.....	12,532
Kind	w. g. p.	w. g. p.	Binder ....do	16,473	16,478
Laboratory No. (see p. 40)	3410	3410	Weathering test:		
Amount ...per cent	4,5,6	6	Time exposed ....days	214	214
Weight of—			Condition	C	B
Fuel briquetted, pounds	2,000	16,000			
Briquets, average, pounds	0.43	0.5			

Extraction analyses.

	Pitch.	Fuels.		Briquets, test 127.
		Utah No. 1.	R. I. No. 1.	
Laboratory No.	3410	3199	3141	.....
Air-drying loss ....per cent	.....	3.80	3.4	0.80
Extracted by CS_2:				
Air-dried ....do	.....	3.98	.02	6.95
As received ....do	79.98	3.83	.02	6.89
Pitch in briquets as received ....do	.....	.....	.....	6.40

UTAH NO. 2.

Bituminous coal from Coalville, Summit County, on the Union Pacific Railroad, was designated Utah No. 2. The coal, as worked at a depth of 295 feet at this place, averages 10 feet in thickness.

The sample consisted of slack through a 1¼-inch screen and was shipped under the supervision of John W. Groves. It was used in steaming tests (on briquets) 402, 403, and 404, and briquetting test 132; also mixed with Rhode Island No. 1 in steaming test 416 (on briquets, see p. 224) and briquetting test 133.

Two mine samples were taken for chemical analysis. Sample 3200 was taken 5,000 feet east of the slope bottom on the 500-foot level, where the coal measured 10 feet 2 inches in thickness. Sample 3201 was taken 4,500 feet east of the slope on the 400-foot level, where the coal measured 10 feet 7 inches in thickness.

CHEMICAL ANALYSES.

Utah No. 2.

	Mine samples.		Car sample.	Steaming tests.[a]		
				402.	403.	404.
Laboratory No.	3200	3201	3259			
Air-drying loss	5.70	5.20	2.30			
Proximate:						
Moisture	14.07	13.86	12.66	11.53	9.32	10.02
Volatile matter	37.21	39.69	38.30	38.91	39.68	39.82
Fixed carbon	42.46	41.19	43.19	43.83	45.05	43.41
Ash	6.26	5.26	5.85	5.73	5.95	6.75
Sulphur	1.28	1.32	1.39	1.36	1.37	1.34
Ultimate:						
Hydrogen				4.70	4.75	4.63
Carbon				72.15	73.30	71.62
Nitrogen				1.27	1.27	1.29
Oxygen				13.86	12.61	13.47
Ash				6.48	6.56	7.50
Sulphur				1.54	1.51	1.49
Calorific value determined (as received) calories	5,817					
Calorific value determined (as received) B. t. u.	10,471					

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Utah No. 2 (briquets.)

	Test 402.	Test 403.	Test 404.
Duration of test ... hours	6.15	2.75	10.08
Heating value of fuel ... B. t. u. per pound dry fuel	12,636	12,791	12,586
Force of draft:			
Under stack damper ... inch water	0.65	0.43	0.55
Above fire ... do	.18	.20	.22
Furnace temperature ... °F	2,054	2,253	
Dry fuel used per square foot of grate surface per hour ... pounds	24.83	16.28	17.19
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	2.87	2.58	2.47
Percentage of rated horsepower of boiler developed	80.4	72.4	69.2
Water apparently evaporated per pound of fuel as fired ... pounds	4.43	6.19	5.64
Water evaporated from and at 212 °F.:			
Per pound of fuel as fired ... do	5.12	7.21	6.48
Per pound of dry fuel ... do	5.78	7.95	7.20
Per pound of combustible ... do	7.23	9.22	8.56
Efficiency of boiler, including grate ... per cent	44.18	60.02	55.24
Fuel as fired:			
Per indicated horsepower hour ... pounds	5.52	3.92	4.36
Per electrical horsepower hour ... do	6.82	4.84	5.39
Dry fuel:			
Per indicated horsepower hour ... do	4.89	3.56	3.93
Per electrical horsepower hour ... do	6.04	4.39	4.85

Remarks.—Test 402 on English briquets, from test 132 (see p. 266), which were broken in two before firing; they burned with some flame and held together well in the fire, with no smoke. Tests 403 and 404 on Renfrow briquets from test 132, which burned with a medium flame and very little smoke, and disintegrated badly in the fire. Very fine dark ash fell through the grate in large quantities, mixed with a good deal of green coal. No clinker formed with the English briquets, and very little with the Renfrow briquets.

BRIQUETTING TESTS.

Utah No. 2.

Test 132.—This coal, sent primarily for briquetting, had all the characteristics of lignite. Oil shale was sent to be used as a binder, but all efforts to use it for this purpose utterly failed. The English briquets with 5 and 6 per cent binder indicated a

shortage of pitch; outer surfaces rough, but crumbly and porous; crumbly at fracture, and broken and fractured surfaces were not firm. Briquets with 7 per cent binder showed improvement over the others, but were not satisfactory; outer surface harder, but could be roughened by rubbing; did not break clean; fractured surfaces not hard. In the drop test, with 6 per cent binder, the 1-inch screen held 54.4 per cent and passed 44.6 per cent. The Renfrow briquets with 6 per cent binder were soft and showed shortage of pitch. Those with 7 per cent binder showed improvement; broke with crumbly fracture and broken surfaces not firm. Eight per cent binder made good briquets, with hard outer surface; broke clean, and broken surfaces firm. For analyses of briquets see page 265 (steaming tests 402, 403, 404).

Test 133.—In this test Rhode Island No. 1, the only available high-volatile coal, was chosen in order to supplement the data of test 127 (p. 264). Test 133 was not successful, as coal showed characteristics of lignite, both in briquetting and burning. The mixture contained 47 per cent of each coal. Briquets with 6 per cent binder were tough and hard; outer surface smooth and very hard, the fracture rough, but clean and firm. No drop tests were made. For analyses of briquets see page 223 (steaming test 416).

		Test 132.		Test 133.
Size as used:				
Over ¼ inch	per cent	0.8		1.2
1/16 inch to ¼ inch	do	8.0		6.0
1/32 inch to 1/16 inch	do	21.4		19.2
1/64 inch to 1/32 inch	do	29.8		25.6
Under 1/64 inch	do	40.0		48.0
Details of manufacture:				
Machine used		Eng.	Renf.	Renf.
Temperature of briquets	°F.	175	149	149
Binder:				
Kind		w. g. p.	w. g. p.	w. g. p.
Laboratory No. (see p. 40)		3,410	3,410	3,410
Amount	per cent	6, 7, 8	5, 6, 7	6
Weight of—				
Fuel briquetted	pounds	29,000	29,000	37,000
Briquets, average	do	3.03	0.42	0.52
Heat value per pound—				
Fuel as received	B. t. u.	10,697	10,697	11,032
Fuel as fired	do	11,180	11,180	11,527
Binder	do	16,478	16,478	16,478
Weathering test:				
Time exposed	days	190	190	190
Condition		D.	C.	E.

Extraction analyses.

		Fuel.		Briquets.	
	Pitch.	Utah No. 2.	R. I. No. 1.	Test 132.	Test 133.
Laboratory No.	3410	3259	3141		
Air-drying loss per cent		2.30	3.40	1.60	1.40
Extracted by CS_2:					
Air-dried do		.27	.02	4.69	6.15
As received do	79.98	.26	.02	4.61	6.06
Pitch in briquets as received do				5.46	7.54

VIRGINIA.

VIRGINIA NO. 5.

Anthracite coal from the bed known as the "Big seam" (Brush Mountain field) 10 miles west of Blacksburg, Montgomery County, was designated Virginia No. 5. The coal, as worked from the outcrop at this place, averages 7 feet 8 inches in thickness.

Two samples were shipped under the supervision of R. T. Carroll, Virginia No. 5 A consisted of pea coal, and was used in steaming tests 476 and 482 and producer-gas test 154. Virginia No. 5 B consisted of 10 tons of slack coal, and was used in steaming test 494 (on briquets) and briquetting tests 187† and 188.

Two mine samples were taken for chemical analysis. Sample 4092 was taken 750 feet south of the opening, where the coal measured 7 feet 10 inches in thickness. Sample 4093 was taken 15 feet away, where the coal measured 7 feet 6 inches in thickness.

CHEMICAL ANALYSES.

Virginia No. 5.

	Mine samples.		Car samples.		Steaming tests.[a]			Briquetting test 187†.[b]
			A.	B.	A.		B.	
					476.	482.	494.	
Laboratory No.	4092	4093	4287	4294	.....	.....	4417	4545
Air-drying loss	3.10	2.40	4.10	7.10	.....	.....	.....	.....
Proximate:								
Moisture	3.51	2.98	4.80	7.52	4.73	4.60	5.02	4.52
Volatile matter	11.06	10.94	10.12	10.29	11.64	11.51	15.52	14.28
Fixed carbon	67.79	64.14	67.05	65.96	65.05	66.51	64.51	65.93
Ash	17.64	21.94	18.03	16.23	18.58	17.38	14.95	15.27
Sulphur	.84	.68	.63	.65	.67	.60	.84	.79
Ultimate:								
Hydrogen	.....	.....	3.91	4.37	3.53	3.58	3.66	3.68
Carbon	.....	.....	69.27	69.05	72.22	73.45	75.82	76.17
Nitrogen	.....	.....	.66	.69	.69	.70	.88	.81
Oxygen	.....	.....	7.50	9.01	3.36	3.42	3.02	2.51
Ash	.....	.....	.....	.....	19.50	18.22	15.74	16.00
Sulphur	.....	.....	.....	.....	.70	.63	.88	.83
Calorific value determined (as received). calories	.....	6,483	6,645	6,607	.....	.....	.....	.....
Calorific value determined (as received). B. t. u.	.....	11,669	11,961	11,893	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

STEAMING TESTS.

Virginia No. 5.

	A.		B.
	Test 476.	Test 482.	Test 494.[a]
Size as used:			
Over 1 inch ... per cent	4.0	2.1	See p. 268.
½ inch to 1 inch ... do	31.1	23.0	
¼ inch to ½ inch ... do	37.7	36.4	
Under ¼ inch ... do	2.72	38.5	
Average diameter ... inch	0.53	0.45	
Duration of test ... hours	9.40	6.53	7.00
Heating value of fuel ... B. t. u. per pound dry fuel	12,472	12,679	13,122

[a] On briquets, equal weights from tests 187† and 188.

STEAMING TESTS—Continued.

Virginia No. 5.

	A.		B.
	Test 476.	Test 482.	Test 494.
Force of draft:			
Under stack damper ... inch water	0.83	0.63	0.84
Above fire ... do	.22	1.03	.20
In ash pit ... do	a .32	.08	.....
Dry fuel used per square foot of grate surface per hour ... pounds	22.74	35.31	20.07
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.56	5.27	3.58
Percentage of rated horsepower of boiler developed	99.7	147.7	100.4
Water apparently evaporated per pound of fuel as fired ... pounds	6.20	5.89	7.02
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	7.46	7.13	8.48
Per pound of dry fuel ... do	7.83	7.47	8.93
Per pound of combustible ... do	10.77	9.67	11.05
Efficiency of boiler, including grate ... per cent	60.63	56.90	65.72
Fuel as fired:			
Per indicated horsepower hour ... pounds	3.79	3.97	3.33
Per electrical horsepower hour ... do	4.68	4.90	4.12
Dry fuel:			
Per indicated horsepower hour ... do	3.61	3.79	3.17
Per electrical horsepower hour ... do	4.46	4.67	3.91

a During the last two hours.

PRODUCER-GAS TEST.

Virginia No. 5 A (pea).

Test 154.—Duration of test, 30 hours. Average electrical horsepower, 199.6. Average B. t. u. per cubic foot of gas, 160.7. Total coal fired, 7,950 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.37	1.33	1.08
Developed at switchboard	1.33	1.29	1.04
Per brake horsepower:			
Commercially available	1.17	1.13	.92
Developed at engine	1.13	1.09	.89
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.49	1.44	1.17
Developed at switchboard	1.44	1.39	1.13
Per brake horsepower:			
Commercially available	1.27	1.22	.99
Developed at engine	1.22	1.18	.96

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.34	Carbon dioxide (CO_2)	10.2
Volatile matter	11.28	Carbon monoxide (CO)	19.1
Fixed carbon	67.24	Hydrogen (H_2)	20.5
Ash	18.14	Methane (CH_4)	1.9
Sulphur	.75	Nitrogen (N_2)	48.2
		Ethylene (C_2H_4)	.1

BRIQUETTING TESTS.

Virginia No. 5 B (slack).

Tests 187† and 188.—Size as used: Over ¼ inch, 0.6 per cent; $\frac{1}{16}$ inch to ¼ inch, 8.8 per cent; $\frac{1}{20}$ inch to $\frac{1}{16}$ inch, 23.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 27.6 per cent; through $\frac{1}{40}$ inch, 39.4 per cent. A very hard, nonporous briquet was made with 6 per cent

binder on the English machine. Renfrow briquets with 7 per cent binder stuck together in piling, showing excess of pitch; otherwise these briquets were satisfactory. This is an exceptionally good briquetting coal, requiring but a small percentage of binder and making briquets with firm, smooth outer surfaces, sharp edges, and characteristic glossy fracture. For analyses of briquets see page 267 (briquets from test 188 under steaming test 494).

	Test 187†.	Test 188.		Test 187†.	Test 188.
Details of manufacture:			Drop test (1-inch screen):		
Machine used	Renf.	Eng.	Held ... per cent	78.5	85.7
Temperatures of briquets ... °F	185	185	Passed ... do	21.5	14.3
Binder—			Tumbler test (1-inch screen):		
Kind	w. g. p.	w. g. p.	Held ... per cent	94.0	89.3
Laboratory No. (see p. 40)	4543	4543	Passed (fines) ... do	6.0	10.7
Amount ... per cent	7	6.25	Fines through 10-mesh sieve ... per cent	96.9	79.1
Weight of—			Weathering test:		
Fuel briquetted, pounds	8,000	4,000	Time exposed ... days	10	6
Briquets, average, pounds	0.457	4.11	Condition	A.	A.
Heat value per pound—			Water absorption:		
Fuel as received, B. t. u.	11,893	11,893	In 19 days ... per cent	14.8	12.6
Fuel as fired ... B. t. u.	12,542	12,463	Average for first 5 days, per cent	2.0	1.12
Binder ... do	16,969	16,969	Specific gravity (apparent)	1.182	1.209

Extraction analysis.

	Pitch.	Fuel.	Briquets.	
			Test 187†.	Test 188.
Laboratory No.	4543	4294	4545	4417
Air-drying loss ... per cent		7.10	3.60	4.10
Extracted by CS_2:				
Air-dried ... do		.29	6.47	5.99
As received ... do	99.66	.27	6.24	5.74
Pitch in briquets as received ... do			6.01	5.51

VIRGINIA NO. 6.

Bituminous coal from the bed locally known as No. 4, 5 miles northwest of Richlands, Tazewell County, on the Norfolk and Western Railway, was designated Virginia No. 6. The coal, as worked from the outcrop at this place, averages 5 feet ½ inch in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of run-of-mine coal and was used in steaming test 507, producer-gas test 160, washing test 198, and coking tests 181 (raw) and 184 (washed coal).

Two mine samples were taken for chemical analysis. Sample 4304 was taken 2,000 feet southeast of the opening, where the coal measured 5 feet 5 inches in thickness. Sample 4305 was taken 1,600 feet east of the opening, where the coal measured 4 feet 8 inches in thickness.

CHEMICAL ANALYSES.

Virginia No. 6.

	Mine samples.		Car sample.	Steaming test 507.[a]
Laboratory No.	4304	4305	4573	.....
Air-drying loss	2.40	1.90	5.00	.....
Proximate:				
Moisture	3.03	2.60	5.62	3.78
Volatile matter	25.82	24.47	23.07	23.08
Fixed carbon	66.53	68.45	61.52	63.85
Ash	4.62	4.48	9.79	9.29
Sulphur	1.70	1.35	1.21	1.16
Ultimate:				
Hydrogen	.....	.....	4.78	4.45
Carbon	.....	.....	73.35	78.41
Nitrogen	.....	.....	1.26	1.35
Oxygen	.....	.....	9.61	4.93
Ash	.....	.....	.....	9.65
Sulphur	.....	.....	.....	1.21
Calorific value determined (as received) calories	.....	8,131	7,369	.....
Calorific value determined (as received) B. t. u.	.....	14,636	13,264	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Virginia No. 6.

		Test 507.
Size as used:		
Over 1 inch	per cent	13.5
½ inch to 1 inch	do	9.0
¼ inch to ½ inch	do	61.2
Under ¼ inch	do	.46
Average diameter	inch	8.87
Duration of test	hours	8.87
Heating value of coal	B. t. u. per pound dry coal	14,177
Force of draft:		
Under stack damper	inch water	.87
Above fire	do	.05
In ash pit	do	.24
Dry coal used per square foot of grate surface per hour	pounds	20.59
Equivalent water evaporated per square foot of water-heating surface per hour	do	3.63
Percentage of rated horsepower of boiler developed		101.8
Water apparently evaporated per pound of coal as fired	pounds	7.01
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	8.49
Per pound of dry coal	do	8.83
Per pound of combustible	do	10.30
Efficiency of boiler, including grate	per cent	60.15
Coal as fired:		
Per indicated horsepower hour	pounds	3.33
Per electrical horsepower hour	do	4.11
Dry coal:		
Per indicated horsepower hour	do	3.20
Per electrical horsepower hour	do	3.95

PRODUCER-GAS TEST.

Virginia No. 6 (run of mine).

Test 160.—Duration of test, 50 hours. Average electrical horsepower, 193.1. Average B. t. u. per cubic foot of gas, 138.1. Total coal fired, 11,000 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.18	1.12	1.00
Developed at switchboard	1.14	1.09	.97
Per brake horsepower:			
Commercially available	1.00	.95	.85
Developed at engine	.97	.92	.83

PRODUCER-GAS TEST—Continued.

Virginia No. 6 (run of mine).

	Coal as fired.	Dry coal.	Combustible.
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.29	1.23	1.10
Developed at switchboard	1.25	1.19	1.07
Per brake horsepower:			
Commercially available	1.09	1.05	.93
Developed at engine	1.06	1.01	.91

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.51	Carbon dioxide (CO_2)	10.5
Volatile matter	22.77	Carbon monoxide (CO)	17.4
Fixed carbon	62.64	Hydrogen (H_2)	14.3
Ash	10.08	Methane (CH_4)	2.0
Sulphur	1.59	Nitrogen (N_2)	55.5
		Ethylene (C_2H_4)	.3

WASHING TESTS.

Virginia No. 6.

Test 198.—Duration of test, 1¼ hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 r. p. m.; stroke, 2½ inches. Raw coal, 8.31 tons; washed coal, 6.75 tons, 81 per cent; refuse, 1.56 tons, 19 per cent.

Analyses.

Sample tested.	Lab. No.	Moisture.	Ash.		Sulphur (per cent).
			Per cent.	Per cent reduction.	
Raw coal, car sample	4573	5.62	9.79	.....	1.21
Washed coal, test 198	4578	6.36	4.38	57	1.30
Refuse	.....	3.64	63.98	.....	6.15

Float and sink tests.

No. of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float— To refuse.	Percentage of float— To total sample.	Sink (per cent).	Analyses. Ash. Per cent.	Ash. Per cent reduction.	Sulphur. Per cent.	Sulphur. Per cent reduction.
On raw coal (preliminary):									
1	¼	1.35	.....	84	16	2.60	54	.95	21
2	¼	1.41	.....	85	15	2.98	48	.92	24
3	¼	1.45	.....	85	15	3.44	42	.95	21
4	¼	1.53	.....	87	13	3.53	41	.97	20
On refuse (float): [a]									
1	.....	1.35	15.30	2.90	.....	4.80	.....	1.39	.....
2	.....	1.41	15.75	2.99	.....	5.35	.....	1.78	.....
3	.....	1.45	15.90	3.02	.....	5.62	.....	1.75	.....
4	.....	1.51	19.25	3.65	.....	9.31	.....	2.79	.....

[a] Figures indicate that finer crushing is advantageous. It will be noted that in the washing test the sulphur shows a higher percentage in the washed coal than it did in the raw coal. This is caused by the reduction of the ash being so much greater than the reduction of the sulphur that the resulting percentage of the sulphur to the washed coal is higher than that of the original sulphur to the raw coal. By formula $Y=\frac{c-M}{c}$, it is found that 13 per cent of the sulphur in the raw coal was removed in washing. Loss of "good coal" in the refuse will not exceed 2.2 per cent. By "good coal" is meant all coal of a quality equal to or better than that of the washed coal.

COKING TESTS.

Virginia No. 6 (run of mine).

		Test 181 (raw).	Test 184 (w.).
Size as used		f. c.	f. c.
Duration of test	hours	50	48
Coal charged	pounds	10,910	11,180
Coke produced	do	6,698	6,150
	per cent	61.39	55.01
Breeze produced	pounds	267	191
	per cent	2.45	1.72
Total yield	do	63.84	56.71

Remarks.—Test 181: Light gray color; dense coke; breakage very irregular. Test 184: Light gray and silvery; good strong coke; washing reduced ash and sulphur.

Analyses.

	Test 181.		Test 184.	
	Coal.	Coke.	Coal.	Coke.
Moisture	5.05	0.38	5.48	0.24
Volatile matter	22.95	1.35	24.77	.32
Fixed carbon	62.11	86.05	64.96	93.73
Ash	9.89	12.22	4.79	5.71
Sulphur	1.49	1.44	1.45	1.24

WASHINGTON.

WASHINGTON NO. 1.

Subbituminous coal from Renton, King County, on the Seattle and Tacoma electric line, and also on a branch of the Great Northern Railway, was designated Washington No. 1. The coal is reached by a slope at this place.

These samples were shipped under the supervision of M. R. Campbell, as follows: Washington No. 1 A consisted of pea coal and was used in producer-gas test 90. Washington No. 1 B consisted of run-of-mine coal, and was used in steaming test 290 and producer-gas tests 89 and 94.

Two mine samples were taken for chemical analysis. Sample 2455 was taken 2,400 feet south of the slope and 4,300 feet from the mouth of the mine. Sample 2456 was obtained 150 feet from the slope and 2,300 feet from the mouth of the mine.

CHEMICAL ANALYSES.

Washington No. 1.

	Mine samples.		Car samples.		Steaming test 290.[a]
Laboratory No.	2455	2456	2687	2686	.....
Air-drying loss	9.90	12.90	10.70	9.60	.....
Proximate:					
Moisture	16.18	17.97	16.04	14.30	15.96
Volatile matter	35.65	35.13	31.39	33.03	34.53
Fixed carbon	39.31	39.12	41.04	41.30	37.43
Ash	8.86	7.78	11.53	11.37	12.08
Sulphur	.46	.43	.61	.72	.58

[a] Proximate analysis of fuel as fired.

CHEMICAL ANALYSES—Continued.

Washington No. 1.

		Mine samples.		Car samples.		Steaming test 290. [a]
Ultimate:						
Hydrogen				5.57	5.73	4.77
Carbon				56.51	57.27	66.09
Nitrogen				1.16	1.17	1.34
Oxygen				24.62	23.74	12.74
Ash						14.37
Sulphur						.69
Calorific value (as received):						
Determined	calories		5,559	5,521	5,671	
	B. t. u.		10,006	9,938	10,208	
Calculated from ultimate analysis	calories			5,438	5,595	
	B. t. u.			9,788	10,071	

[a] Ultimate analysis of dry fuel figured from car sample.

STEAMING TEST.

Washington No. 1 B (run of mine).

		Test 290.
Size as used:		
Over 1 inch	per cent	38.9
½ inch to 1 inch	do	23.9
¼ inch to ½ inch	do	14.
Under ¼ inch	do	22.
Duration of test	hours	10.0
Heating value of coal	B. t. u. per pound dry coal	11,772
Force of draft:		
Under stack damper	inch water	0.59
Above fire	do	.12
Furnace temperature	°F.	2,047
Dry coal used per square foot of grate surface per hour	pounds	19.63
Equivalent water evaporated per square foot of water-heating surface per hour	do	2.92
Percentage of rated horsepower of boiler developed		81.8
Water apparently evaporated per pound of coal as fired	pounds	5.22
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	6.25
Per pound of dry coal	do	7.44
Per pound of combustible	do	9.26
Efficiency of boiler, including grate	per cent	61.03
Coal as fired:		
Per indicated horsepower hour	pounds	4.52
Per electrical horsepower hour	do	5.59
Dry coal:		
Per indicated horsepower hour	do	3.80
Per electrical horsepower hour	do	4.69

PRODUCER-GAS TESTS.

Washington No. 1.

		A.	B.	
		Test 90.	Test 89.	Test 94.
Size as shipped		Pea.	r. o. m.	r. o. m.
Size as used:				
Over 1 inch	per cent	9	45	68
½ inch to 1 inch	do	35	10	10
¼ inch to ½ inch	do	31	15	9
Under ¼ inch	do	25	30	13
Duration of test	hours	40	40	14
Average electrical horsepower		144.2	156.2	135.6
Average B. t. u. per cubic foot of gas		145.9	159.2	144.1
Total coal fired	pounds	18,900	16,450	6,550

PRODUCER-GAS TESTS—Continued.

Washington No. 1.

	Test 90 (A.)			Test 89 (B).			Test 94 (B).		
	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).									
Per electrical horsepower:									
Commercially available	3.53	2.96	2.51	2.83	2.37	1.99	2.52	2.12	1.77
Developed at switch board	3.28	2.75	2.34	2.63	2.21	1.86	2.39	2.01	1.68
Per brake horsepower:									
Commercially available	3.00	2.52	2.14	2.40	2.01	1.69	2.14	1.80	1.50
Developed at engine	2.79	2.34	1.99	2.24	1.88	1.58	2.03	1.71	1.43
Equivalent used by producer plant (pounds).									
Per electrical horsepower:									
Commercially available	3.71	3.11	2.64	3.03	2.54	2.14	2.73	2.29	1.91
Developed at switch board	3.44	2.89	2.45	2.82	2.37	1.99	2.59	2.17	1.81
Per brake horsepower:									
Commercially available	3.15	2.64	2.24	2.57	2.16	1.81	2.32	1.94	1.62
Developed at engine	2.93	2.45	2.08	2.40	2.01	1.69	2.20	1.85	1.54

Analyses.

	Test 90.	Test 89.	Test 94.		Test 90.	Test 89.	Test 94.
Coal.				*Gas by volume.*			
Moisture	16.17	16.21	16.02	Carbon dioxide (CO_2)	11.3	13.4	12.6
Volatile matter	34.00	34.07	33.27	Carbon monoxide (CO)	15.4	14.5	13.9
Fixed carbon	37.27	36.35	36.81	Hydrogen (H_2)	10.5	16.7	12.8
Ash	12.56	13.37	13.90	Methane (CH_4)	3.6	3.8	2.6
Sulphur	.53	.58	.59	Nitrogen (N_2)	59.2	51.6	57.4
				Oxygen (O_2)	.0	.0	.2
				Ethylene (C_2H_4)	.....	.....	.7

WASHINGTON NO. 2.

Bituminous coal from Roslyn, Kittitas County, on the Northern Pacific Railway, was designated Washington No. 2. The coal is worked at a depth of 625 feet at this place.

The sample, consisting of lump coal loaded under the supervision of M. R. Campbell, was used in steaming tests 359, 360, 361, and (on briquets) 412; producer-gas test 112; coking test 135; cupola tests 97 and 134; and briquetting test 125.

Two mine samples were taken for chemical analysis. Sample 2457 was taken about 6,000 feet from the mouth of the mine. Sample 2458 was taken about 2,000 feet from the foot of the shaft.

CHEMICAL ANALYSES.

Washington No. 2.

	Mine samples.		Car sample.	Steaming tests.[a]			
				359.	360.	361.	412.
Laboratory No	2458	2457	3098				
Air-drying loss	1.30	.90	1.30				
Proximate:							
Moisture	3.39	3.36	3.16	3.16	3.61	3.59	2.66
Volatile matter	37.34	36.15	36.49	36.49	35.63	35.97	37.39
Fixed carbon	48.88	46.58	48.09	48.09	48.95	48.85	48.89
Ash	10.39	13.91	12.26	12.26	11.81	11.59	11.06
Sulphur	.33	.36	.38	.38	.39	.37	.39
Ultimate:							
Hydrogen			5.15	4.96	4.98	4.99	4.86
Carbon			69.35	71.62	71.95	72.16	73.02
Nitrogen			1.24	1.28	1.29	1.29	1.48
Oxygen			11.62	9.09	9.12	9.15	8.88
Ash				12.66	12.25	12.03	11.36
Sulphur				.39	.41	.38	.40
Calorific value (as received):							
Determined, calories	7,137		6,992				
Determined, B. t. u.			12,586				
Calculated from ultimate analysis, calories			6,879				
Calculated from ultimate analysis, B. t. u.			12,382				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Washington No. 2 (lump).

	Test 359.	Test 360.	Test 361.	Test 412.
Size as used:				
Over 1 inch, per cent	20.9	41.4	33.5	See p. 277
½ inch to 1 inch, do	21.3	22.3	22.8	
¼ inch to ½ inch, do	18.0	15.3	15.8	
Under ¼ inch, do	39.8	21.0	27.9	
Duration of test, hours	10.0	10.05	10.0	9.47
Heating value of fuel, B. t. u. per pound dry fuel	12,996	13,059	13,095	13,243
Force of draft:				
Under stack damper, inch water	0.60	0.67	0.68	0.63
Above fire, do	.13	.12	.12	.11
Furnace temperature, °F.	2,362	2,469	2,405	2,155
Dry fuel used per square foot of grate surface per hour, pounds	19.83	22.69	21.92	19.78
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	3.47	3.86	3.82	3.54
Percentage of rated horsepower of boiler developed	97.4	108.4	107.1	99.3
Water apparently evaporated per pound of fuel as fired, pounds	7.13	6.93	7.08	7.49
Water evaporated from and at 212 °F.:				
Per pound of fuel as fired, pounds	8.50	8.23	8.42	8.74
Per pound of dry fuel, do	8.78	8.54	8.73	8.98
Per pound of combustible, do	10.27	9.86	10.07	10.22
Efficiency of boiler, including grate, per cent	65.25	63.15	64.38	65.48
Fuel as fired:				
Per indicated horsepower hour, pounds	3.33	3.44	3.36	3.24
Per electrical horsepower hour, do	4.11	4.24	4.15	3.99
Dry fuel:				
Per indicated horsepower hour, do	3.22	3.31	3.24	3.15
Per electrical horsepower hour, do	3.98	4.09	4.00	3.89

Remarks.—Test 412 on briquets. English briquets burned very freely and cracked open to a depth of 2 inches, but coked and held together well. Renfrow briquets made a hotter fire than the others, probably owing to the fact that they were small and made a more compact fuel bed. The different percentages of pitch do not affect the burning qualities. No smoke. Refuse: Clinker was heavy and was brittle when hot, and slightly porous. Ash was heavy and of a reddish-brown color.

PRODUCER-GAS TEST.

Washington No. 2 (lump).

Test 112.—Duration of test, 35 hours. Average electrical horsepower 195.7. Average B. t. u. per cubic foot of gas, 168.6. Total coal fired, 9,300 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.44	1.38	1.18
Developed at switchboard	1.36	1.30	1.12
Per brake horsepower:			
Commercially available	1.22	1.17	1.00
Developed at engine	1.15	1.11	.95
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.52	1.46	1.25
Developed at switchboard	1.44	1.38	1.18
Per brake horsepower:			
Commercially available	1.29	1.24	1.06
Developed at engine	1.22	1.17	1.01

Analyses.

Coal.		*Gas by volume.*	
Moisture	4.01	Carbon dioxide (CO_2)	7.9
Volatile matter	34.61	Carbon monoxide (CO)	22.2
Fixed carbon	47.49	Hydrogen (H_2)	15.4
Ash	13.89	Methane (CH_4)	2.6
Sulphur	.38	Nitrogen (N_2)	51.5
		Ethylene (C_2H_4)	.4

COKING TEST.

Washington No. 2 (lump).

Test 135.—Size as used: Raw, finely crushed. Duration of test, 36 hours; coal charged, 10,000 pounds; coke produced, 5,477 pounds, 54.77 per cent; breeze produced, 444 pounds, 4.44 per cent. Total percentage yield, 59.21. Light gray, with deposit of carbon; fingered and brittle. Ash should be lowered and coke probably otherwise improved by washing.

Analyses.

	Coal.	Coke.
Moisture	3.07	1.02
Volatile matter	37.42	2.10
Fixed carbon	47.35	77.53
Ash	12.16	19.35
Sulphur	.44	.44

Cupola tests of coke made from Washington No. 2 coal.

CHARGE.

Cupola test No.	Test No.	Coke.[a] Specific gravity.	Coke.[a] Ratio iron to coke.	Fluidity strip full.	Materials.	Divisions of charge. 1.	2.	3.	4.	5.	Total.
				Per ct.		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
97	135	1.90	7	91.60	Coke	190	60	60	60	60	430
					Pig iron	570	420	420	420	420	2,250
					Scrap	190	140	140	140	140	750
134	135	1.90	7	97.22	Coke	200	58	58	57	57	430
					Pig iron	600	413	413	412	412	2,250
					Scrap	200	138	138	137	137	750

[a] Phosphorus in coke, 0.0847 per cent.

Cupola tests of coke made from Washington No. 2 coal—Continued.

RECORD OF MELT.

Cupola test No.	Blast pressure.		Iron running in—	Weight of iron.			Melting.				Recovered.	
	On at—	Maximum.		Poured.	Additional melted.	Total.	Time.	Rate per hour.	Ratio iron to coke	Loss.	Iron.	Coke.
		Oz.	*Min.*	*Lbs.*	*Lbs.*	*Lbs.*	*Min.*	*Lbs.*		*Per ct.*	*Lbs.*	*Lbs.*
97	9.41 a. m....	7	9	903	299	1,202	29	2,487	3.03	8.96	1,529	33
134	4.27 p. m...	7	7	1,411	365	1,776	30	3,552	4.46	3.40	1,112	32

LADLE RECORD.

Ladle No.	Test 97.		Test 134.		Ladle No.	Test 97.		Test 134.	
	Pounds.	Time (a.m.).	Pounds.	Time (p. m.).		Pounds.	Time (a. m.).	Pounds.	Time (p. m.)
1.....	24	9.53	78	4.43	12.....	51	10.13	73	4.55
2.....	36	9.56	30	4.43½	13.....	55	10.13½	68	4.55½
3.....	83	10.00	80	4.46	14.....	94	10.15	72	4.57
4.....	91	10.04	44	4.46½	15.....	30	10.18	68	4.57½
5.....	96	10.04½	78	4.48	16.....	9	10.19	107	4.58
6.....	17	10.05	41	4.48½	17.....	.....	.....	79	4.59
7.....	58	10.08	73	4.49	18.....	.....	.....	21	5.00
8.....	76	10.09	98	4.50	19.....	.....	.....	56	5.01½
9.....	64	10.10	26	4.50½	20.....	.....	.....	59	5.02
10.....	59	10.10½	88	4.51½	21.....	.....	.....	88	5.04
11.....	60	10.12	84	4.53					

Remarks.—Test 97: Iron cold.

BRIQUETTING TEST.

Washington No. 2 (lump).

Test 125.—Size as used: Over ¼ inch, 2.4 per cent; $\frac{1}{10}$ inch to ¼ inch, 11 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 19.6 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 26.2 per cent; through $\frac{1}{40}$ inch, 40.8 per cent. Kind of binder, water-gas pitch; laboratory No. 3410 (see p. 40). Weight of fuel briquetted, 12,000 pounds. B. t. u. per pound of coal as received 12,586; per pound of briquets as fired, 12,890; per pound of binder, 16,478.

English briquets, average weight 3.24 pounds, proved that 5.5 per cent binder was insufficient, as shown by general lack of cohesion at edges and surfaces of whole briquets and of fracture. With 6 per cent binder, briquets were still crumbly, but better than those with 5.5 per cent. With 6.5 and 7 per cent binder, briquets were cohesive, with firm edges and surfaces hard and smooth. In the drop test with 6 per cent binder the 1-inch screen held 87.4 per cent and passed 12.6 per cent. In the weathering test all briquets were exposed 214 days; condition of those with 5.5 per cent binder C, of the others B.

Renfrow briquets, average weight 0.46 pound, in weathering test were exposed 214 days; condition of those with 6.5 per cent binder, C; of those with 7 and 7.5 per cent binder, B.

For analyses of briquets see page 275 (steaming test 412).

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 125.
Laboratory No.....	3410	3098	.....
Air-drying loss.....per cent..	.....	1.30	0.20
Extracted by CS_2:			
Air dried.....do....	.....	1.26	6.90
As received.....do....	79.98	1.24	6.89
Pitch in briquets as received.....do....	.....	.....	7.19

WEST VIRGINIA.

WEST VIRGINIA NO. 11.[a]

A car of bone coal from Pocahontas bed No. 3 at Zenith (Crumpler station), Monroe County, on the Norfolk and Western Railway, was designated West Virginia No. 11 B. This sample was shipped under the supervision of John W. Groves and used in producer-gas test 161.

This carload was picked up by hand beside the tipple, where it had accumulated in ridges along the tracks by being thrown away while cleaning and loading cars. The process of picking up the lumps by hand naturally eliminated the fine coal that was broken off the lumps, making a smaller per cent of good coal than would be the case in loading from a bin.

No mine samples were taken at the time of shipment. One sample of representative bone coal was carefully cleaned of all good coal adhering to it and sent in for chemical analysis.

CHEMICAL ANALYSIS.

West Virginia No. 11 B (bone coal).

Laboratory No	42.31
Air-drying loss	.60
Moisture	1.02
Volatile matter	9.08
Fixed carbon	44.47
Ash	45.43
Sulphur	.30

PRODUCER-GAS TEST.

West Virginia No. 11 B (bone coal).

Test 161.—Duration of test, 50 hours. Average electrical horsepower, 194.3. Average B. t. u. per cubic foot of gas, 144.0. Total coal fired, 18,900 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.00	1.99	1.12
Developed at switchboard	1.95	1.94	1.09
Per brake horsepower:			
Commercially available	1.70	1.69	.95
Developed at engine	1.65	1.64	.92

Analyses.

Coal.		*Gas by volume.*	
Moisture	0.47	Carbon dioxide (CO_2)	9.7
Volatile matter	8.83	Carbon monoxide (CO)	19.5
Fixed carbon	46.96	Hydrogen (H_2)	16.6
Ash	43.74	Methane (CH_4)	1.6
Sulphur	.27	Nitrogen (N_2)	52.6

[a] For other tests of coal from this mine, made during 1904, see Bull. U. S. Geol. Survey No. 261, 1905, pp. 58, 83, 129; Prof. Paper U. S. Geol. Survey No. 48, 1906, pp. 133, 259, 905, 1365.

WEST VIRGINIA NO. 16.[a]

Bituminous lump coal from Monongah, Marion County, on the Baltimore and Ohio Railroad, was designated West Virginia No. 16 A. Coal over a ¾-inch screen, loaded under the supervision of J. S. Burrows, was used in steaming tests 304 and 305.

CHEMICAL ANALYSES.

West Virginia No. 16 A.

	Steaming tests.[a]			Steaming tests.[a]	
	304.	305.		304.	305.
Proximate:			Ultimate:		
Moisture	4.12	6.79	Hydrogen	4.99	4.98
Volatile matter	33.83	31.71	Carbon	77.43	77.38
Fixed carbon	54.05	53.61	Nitrogen	1.58	1.57
Ash	8.00	7.89	Oxygen	6.44	6.44
Sulphur	1.17	1.09	Ash	8.34	8.46
			Sulphur	1.22	1.17

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

West Virginia No. 16 A (lump).

		Test 304.	Test 305.
Size as used:			
Over 1 inch	per cent	50.6	33.9
½ inch to 1 inch	do	22.8	19.6
¼ inch to ½ inch	do	10.1	19.0
Under ¼ inch	do	16.5	27.5
Duration of test	hours	5.3	5.33
Kind of grate		Rocking.	
Heating value of coal	B. t. u. per pound dry coal	13,896	13,964
Force of draft:			
Under stack damper	inch water	0.42	0.49
Above fire	do	.14	.09
Furnace temperature	° F.	2,864	2,548
Dry coal used per square foot of grate surface per hour	pounds	20.88	16.37
Equivalent water evaporated per square foot of water-heating surface per hour,	pounds	3.85	3.33
Percentage of rated horsepower of boiler developed		108.0	93.4
Water apparently evaporated per pound of coal as fired	pounds	8.18	7.89
Water evaporated from and at 212° F.:			
Per pound of coal as fired	do	9.88	9.50
Per pound of dry coal	do	10.30	10.20
Per pound of combustible	do	11.56	11.29
Efficiency of boiler, including grate	per cent	71.58	70.54
Coal as fired:			
Per indicated horsepower hour	pounds	2.86	2.98
Per electrical horsepower hour	do	3.53	3.68
Dry coal:			
Per indicated horsepower hour	do	2.74	2.77
Per electrical horsepower hour	do	3.39	3.42

WEST VIRGINIA NO. 22.

Bituminous coal from a bed at Hernshaw, Kanawha County, on the Chesapeake and Ohio Railway, was designated "West Virginia No. 22." This coal has not been definitely correlated with any of the well-known coals of the region. As mined at the outcrop, it is 5 feet 9¾ inches in average thickness.

Two samples were shipped under the supervision of John W. Groves. West Virginia No. 22 A consisted of screenings through a

[a] For other tests of this coal, made during 1905, see Bull. U. S. Geol. Survey No. 290, 1906, p. 203.

1¼-inch screen, and was used in steaming tests 446, 447, and (washed coal) 454, and in washing test 186. West Virginia No. 22 B consisted of run-of-mine coal, and was used in steaming test 438.

Two mine samples were taken for chemical analysis. Sample 3456 was taken 400 feet east of the opening, where the coal measured 6 feet 6½ inches in thickness. Sample 3457 was taken 1,200 feet east of the opening, where the coal measured 4 feet 3 inches in thickness.

CHEMICAL ANALYSES.

West Virginia No. 22.

	Mine samples.		Car sample.	Steaming tests.[a]			
				A.			B.
				446.	447.	454.	438.
Laboratory No.	3456	3457	3905	.....	.....	.....	.....
Air-drying loss	0.90	1.50	2.00	.....	.....	.....	.....
Proximate:							
Moisture	2.75	3.49	3.42	5.44	5.55	5.24	3.42
Volatile matter	35.49	33.67	33.49	29.31	29.65	33.67	33.49
Fixed carbon	56.27	56.40	55.27	51.64	51.33	54.99	55.27
Ash	5.49	6.44	7.82	13.61	13.47	6.10	7.82
Sulphur	.63	.63	.83	.95	1.04	.90	.83
Ultimate:							
Hydrogen	.....	.....	5.27	4.72	4.72	5.17	4.96
Carbon	.....	.....	74.49	72.02	72.03	78.82	77.13
Nitrogen	.....	.....	1.20	1.15	1.15	1.26	1.24
Oxygen	.....	.....	10.39	6.72	6.74	7.36	7.71
Ash	.....	.....	.....	14.39	14.26	6.44	8.10
Sulphur	.....	.....	.....	1.00	1.10	.95	.86
Calorific value determined (as received) calories	7,674	7,674	7,492	.....	.....	.....	.....
Calorific value determined (as received) B. t. u.	13,813	13,813	13,486	.....	.....	.....	.....

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

West Virginia No. 22.

	A.			B.
	Test 446.	Test 447.	Test 454 (w.).	Test 438.
Size as used:				
Over 1 inch ... per cent	9.7	5.6	15.2	53.6
½ inch to 1 inch ... do	17.8	15.8	26.8	20.0
¼ inch to ½ inch ... do	21.5	20.8	21.7	10.0
Under ¼ inch ... do	51.0	57.8	36.3	16.4
Average diameter ... inches	0.48	0.41	0.61	1.27
Duration of test ... hours	10.22	9.68	.....	9.55
Heating value of coal ... B. t. u. per pound dry coal	12,838	12,843	14,152	13,963
Force of draft:				
Under stack damper ... inch water	0.81	0.81	0.75	0.79
Above fire ... do	.17	.19	.16	.09
Furnace temperature ... °F	2,616	2,801	2,793	.....
Dry coal used per square foot of grate surface per hour, pounds	18.94	20.22	20.99	21.97
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.08	3.54	3.93	4.20
Percentage of rated horsepower of boiler developed	86.4	99.1	110.3	117.6
Water apparently evaporated per pound of coal as fired, pounds	6.58	7.06	7.42	7.89
Water evaporated from and at 212° F.:				
Per pound of coal as fired ... pounds	7.71	8.28	8.90	9.24
Per pound of dry coal ... do	8.16	8.76	9.39	9.57
Per pound of combustible ... do	10.00	10.61	10.33	10.60
Efficiency of boiler, including grate ... per cent	61.38	65.87	64.08	66.19
Coal as fired:				
Per indicated horsepower hour ... pounds	3.67	3.42	3.18	3.06
Per electrical horsepower hour ... do	4.53	4.22	3.92	3.78
Dry coal:				
Per indicated horsepower hour ... do	3.47	3.23	3.01	2.96
Per electrical horsepower hour ... do	4.28	3.99	3.72	3.65

WASHING TEST.

West Virginia No. 22 A (nut and slack).

Test 186.—Jig used, Stewart. Raw coal, 38,250 pounds. Washed coal, 32,250 pounds; 84 per cent. Refuse, 6,000 pounds; 16 per cent.

Analyses.

	Raw coal.	Washed coal.
Moisture	4.59	7.06
Volatile matter	33.38	33.34
Fixed carbon	52.23	53.84
Ash	9.80	5.76
Sulphur	1.01	.97

WEST VIRGINIA NO. 23.

Bituminous coal from the Cedar Grove bed, one-fourth mile northeast of Monarch, Kanawha County, on the Kanawha and Michigan Railroad, was designated West Virginia No. 23. The coal, as worked from the outcrop at this place, averages 3 feet 1½ inches in thickness.

Two samples were shipped under the supervision of John W. Groves. West Virginia No. 23 A consisted of run-of-mine coal and was used in steaming tests 439 and 440. West Virginia No. 23 B consisted of slack through a 1½-inch screen, and was used in steaming tests 444 (washed) and 445 and washing test 180.

Two mine samples were taken for chemical analysis. Sample 3458 was taken 1,500 feet north of the opening, where the coal measured 3 feet 1¼-inches in thickness. Sample 3459 was taken 1,500 feet northwest of the opening, where the coal measured 3 feet 2 inches in thickness.

CHEMICAL ANALYSES.

West Virginia No. 23.

	Mine samples.		Car samples.		Steaming tests.[a]			
			A.	B.	A.		B.	
					439.	440.	444.	445.
Laboratory No.	3458	3459	3965	3625				
Air-drying loss	1.40	2.50	.60	1.70				
Proximate:								
Moisture	3.13	4.17	2.05	3.25	2.05	2.61	4.06	2.44
Volatile matter	35.51	35.36	34.71	34.61	34.71	34.15	35.70	33.30
Fixed carbon	57.82	54.17	55.14	54.56	55.14	53.96	55.44	53.67
Ash	3.54	6.30	8.10	7.58	8.10	9.28	4.80	10.59
Sulphur	.59	1.24	1.35	1.22	1.35	1.52	.95	1.40
Ultimate:								
Hydrogen			5.08	5.23	4.95	4.88	5.20	4.86
Carbon			75.56	75.27	77.14	75.91	80.44	75.06
Nitrogen			1.18	1.43	1.21	1.18	1.53	1.42
Oxygen			8.73	9.27	7.05	6.94	6.84	6.38
Ash					8.27	9.53	5.00	10.85
Sulphur					1.38	1.56	.99	1.43
Calorific value determined (as received) calories	7,757		7,615	7,513				
B. t. u.	13,963		13,707	13,523				

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

West Virginia No. 23.

	A.		B.	
	Test 439.	Test 440.	Test 444 (w.).	Test 445.
Size as used:				
Over 1 inch ..... per cent	56.3	32.9	12.1	25.2
½ inch to 1 inch ..... do	21.9	20.0	23.2	21.6
¼ inch to ½ inch ..... do	12.0	15.4	24.6	16.6
Under ¼ inch ..... do	9.8	31.7	40.1	36.6
Average diameter ..... inches	1.31	.87	.56	.70
Duration of test ..... hours	9.95	9.83	10.05	10.00
Heating value of coal ..... B. t. u. per pound dry coal	13,995	13,781	14,483	13,498
Force of draft:				
Under stack damper ..... inch water	0.77	0.75	0.78	0.77
Above fire ..... do	.12	.12	.10	.13
Furnace temperature ..... ° F	2,657	2,572	2,536	2,638
Dry coal used per square foot of grate surface per hour, pounds	19.98	18.82	17.51	19.11
Equivalent water evaporated per square foot of water-heating surface per hour ..... pounds	3.56	3.41	3.14	3.42
Percentage of rated horsepower of boiler developed	99.7	95.6	88.0	95.9
Water apparently evaporated per pound of coal as fired, pounds	7.49	7.63	7.37	7.47
Water evaporated from and at 212° F.:				
Per pound of coal as fired ..... pounds	8.73	8.84	8.61	8.75
Per pound of dry coal ..... do	8.92	9.08	8.98	8.97
Per pound of combustible ..... do	10.20	10.49	9.92	10.65
Efficiency of boiler, including grate ..... per cent	61.55	63.62	59.88	64.17
Coal as fired:				
Per indicated horsepower hour ..... pounds	3.24	3.20	3.28	3.23
Per electrical horsepower hour ..... do	4.00	3.95	4.05	3.99
Dry coal:				
Per indicated horsepower hour ..... do	3.17	3.11	3.15	3.15
Per electrical horsepower hour ..... do	3.91	3.84	3.89	3.89

WASHING TEST.

West Virginia No. 23 B (nut and slack).

Test 180.—Jig used, Stewart. Raw coal, 36,000 pounds. Washed coal, 33,980 pounds; 94 per cent. Refuse, 2,020 pounds; 6 per cent. Analyses: For analyses of the fuel used see page 281 (sample 3625). Analysis of the washed coal: Moisture, 4.24; ash, 4.87; sulphur, 0.93.

WEST VIRGINIA NO. 24.

A sample of bone coal from the Pocahontas bed No. 3 at Gary, McDowell County, on the Norfolk and Western Railway, was designated West Virignia No. 24. This sample was shipped under the supervision of A. K. Adams and was used in producer-gas test 162.

PRODUCER-GAS TEST.

West Virginia No. 24 (bone coal).

Test 162.—Duration of test, 50 hours. Average electrical horsepower, 148.8. Average B. t. u. per cubic foot of gas, 106.3. Total coal fired, 11,000 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.55	1.51	1.07
Developed at switchboard	1.48	1.44	1.02
Per brake horsepower:			
Commercially available	1.32	1.28	.91
Developed at engine	1.26	1.22	.87

Analyses.

Coal.		*Gas by volume.*	
Moisture	2.91	Carbon dioxide (CO_2)	12.4
Volatile matter	11.81	Carbon monoxide (CO)	14.0
Fixed carbon	57.19	Hydrogen (H_2)	13.8
Ash	28.08	Methane (CH_4)	1.2
Sulphur	.54	Nitrogen (N_2)	58.6

WEST VIRGINIA NO. 25.

Bituminous coal from the Black Band bed, 8 miles southeast of Charleston, Kanawha County, on the Chesapeake and Ohio Railway, was designated West Virginia No. 25. The coal, as worked from the outcrop at this place, averages 2 feet 9¾ inches in thickness.

One sample, shipped under the supervision of John W. Groves, consisted of lump coal over a 1¼-inch screen, and was used in producer-gas test 156 and coking test 175.

Two mine samples were taken for chemical analysis. Sample 4290 was taken 1,300 feet south of the opening, where the coal measured 2 feet 8¾ inches in thickness. Sample 4291 was taken 800 feet west of the opening, where the coal measured 2 feet 11 inches in thickness.

CHEMICAL ANALYSES.

West Virginia No. 25.

	Mine samples.		Car sample.			Mine samples.	Car sample.
Laboratory No.	4290	4291	4360	Ultimate:			
Air-drying loss	1.80	2.10	2.30	Hydrogen			5.16
Proximate:				Carbon			72.89
Moisture	3.46	3.91	4.21	Nitrogen			1.40
Volatile matter	34.55	34.83	35.41	Oxygen			12.69
Fixed carbon	53.79	54.48	53.16	Calorific value determined (as received)	calories	7,484	7,433
Ash	8.20	6.78	7.22		B. t. u.	13,471	13,379
Sulphur	.58	.64	.64				

PRODUCER-GAS TEST.

West Virginia No. 25 (lump).

Test 156.—Duration of test, 50 hours. Average electrical horsepower, 199.2. Average B. t. u. per cubic foot of gas, 171.6. Total coal fired, 13,000 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.35	1.30	1.19
Developed at switchboard	1.31	1.26	1.15
Per brake horsepower:			
Commercially available	1.15	1.11	1.01
Developed at engine	1.11	1.07	.98
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	1.42	1.37	1.25
Developed at switchboard	1.37	1.32	1.21
Per brake horsepower:			
Commercially available	1.21	1.16	1.06
Developed at engine	1.17	1.12	1.03

Analyses.

Coal.		*Gas by volume.*	
Moisture	3.83	Carbon dioxide (CO_2)	7.9
Volatile matter	34.34	Carbon monoxide (CO)	23.4
Fixed carbon	53.61	Hydrogen (H_2)	17.1
Ash	8.22	Methane (CH_4)	2.1
Sulphur	.62	Nitrogen (N_2)	49.1
		Ethylene (C_2H_4)	.4

COKING TEST.

West Virginia No. 25 (lump).

Test 175.—Size as used: Raw, finely crushed. Duration of test, 43 hours. Coal charged, 11,340 pounds. Coke produced, 6,920 pounds, 61.02 per cent. Breeze produced, 381 pounds, 3.36 per cent. Total yield, 64.38 per cent. Good strong coke; gray color with a little silvery deposit of carbon.

Analyses.

	Coal.	Coke.
Moisture	4.56	0.30
Volatile matter	34.38	.49
Fixed carbon	53.39	86.71
Ash	7.67	12.50
Sulphur	.61	.47

WYOMING.

WYOMING NO. 4.

Bituminous coal from Hanna, Carbon County, on the Union Pacific Railroad, was designated Wyoming No. 4. The coal, as worked at a depth of 387 feet at this place, averages 35 feet in thickness.

This sample, consisting of run-of-mine coal shipped under the supervision of John W. Groves, was used in steaming test 399 and producer-gas test 123.

Four mine samples were taken for analysis. Sample 3160 was taken 1,900 feet south of the slope. Sample 3161 was taken 2,000 feet south of the slope. Sample 3162 was taken 1,700 feet south of the slope. Sample 3163 was taken immediately above the point where sample 3162 was taken. The two benches combined measured 35 feet.

CHEMICAL ANALYSES.

Wyoming No. 4.

	Mine samples.				Car samples.		Steaming test 399.[a]
Laboratory No.	3160	3161	3162	3163	[b] 3363	[c] 3396	.....
Air-drying loss	3.80	4.10	4.00	3.50	2.30	3.80	.....
Proximate:							
Moisture	12.32	12.66	11.49	11.73	11.30	12.40	12.40
Volatile matter	40.80	40.36	40.38	41.30	40.32	39.75	39.75
Fixed carbon	41.69	43.10	42.24	41.40	41.07	41.08	41.08
Ash	5.19	3.88	5.89	5.57	7.31	6.77	6.77
Sulphur	.23	.21	.44	.29	.28	.26	.26

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] *Sample from producer-gas test 123 treated as car sample.*
[c] *Sample from steaming test 399 treated as car sample.*

CHEMICAL ANALYSES—Continued.

Wyoming No. 4.

	Mine samples.				Car samples.		Steaming test 399.
Ultimate:							
Hydrogen					5.56	6.37	5.70
Carbon					61.24	61.58	70.30
Nitrogen					.88	.85	.97
Oxygen					24.73	24.17	15.00
Ash							7.73
Sulphur							.30
Calorific value (as received):							
Determined, calories	6,168				5,975	5,948	
Determined, B. t. u.	11,102				10,755	10,706	
Calculated from ultimate analysis, calories					5,806	6,136	
Calculated from ultimate analysis, B. t. u.					10,451	11,045	

STEAMING TEST.

Wyoming No. 4 (run of mine).

	Test 399.
Size as used:	
Over 1 inch ... per cent	23.1
½ inch to 1 inch ... do	18.3
¼ inch to ½ inch ... do	19.2
Under ¼ inch ... do	39.4
Duration of test ... hours	10.02
Heating value of coal ... B. t. u. per pound dry coal	12,222
Force of draft:	
Under stack damper ... inch water	0.60
Above fire ... do	.38
Furnace temperature ... °F	26.26
Dry coal used per square foot of grate surface per hour ... pounds	23.97
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.40
Percentage of rated horsepower of boiler developed	95.2
Water apparently evaporated per pound of coal as fired ... pounds	5.32
Water evaporated from and at 212° F.:	
Per pound of coal as fired ... do	6.22
Per pound of dry coal ... do	7.10
Per pound of combustible ... do	8.18
Efficiency of boiler, including grate ... per cent	56.10
Coal as fired:	
Per indicated horsepower hour ... pounds	4.55
Per electrical horsepower hour ... do	5.62
Dry coal:	
Per indicated horsepower hour ... do	3.98
Per electrical horsepower hour ... do	4.92

PRODUCER-GAS TEST.

Wyoming No. 4 (run of mine).

Test 123.—Duration of test, 50 hours. Average electrical horsepower, 195.5. Average B. t. u. per cubic foot of gas, 151.6. Total coal fired, 20,200 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.20	1.95	1.79
Developed at switchboard	2.07	1.83	1.68
Per brake horsepower:			
Commercially available	1.87	1.66	1.52
Developed at engine	1.76	1.56	1.43
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.38	2.11	1.94
Developed at switchboard	2.24	1.99	1.83
Per brake horsepower:			
Commercially available	2.02	1.80	1.65
Developed at engine	1.91	1.69	1.55

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	12.2
Carbon monoxide (CC)	16.4
Hydrogen (H_2)	15.1
Methane (CH_4)	2.7
Nitrogen (N_2)	53.2
Ethylene (C_2H_4)	.4

WYOMING NO. 5.

Bituminous coal from Rock Springs, Sweetwater County, on the Union Pacific Railroad, was designated Wyoming No. 5. The coal, as worked at a depth of 493 feet at this place, averages 7 feet 6 inches in thickness.

The sample, consisting of run-of-mine coal, shipped under the inspection of John W. Groves, was used in producer-gas test 114 and coking test 132.

Two mine samples were taken for chemical analysis. Sample 3164 was taken 5,200 feet north of the slope, where the coal measured 7 feet 6 inches in thickness. Sample 3165 was taken 7,000 feet north of the slope, where the coal measured 7 feet 2 inches in thickness.

CHEMICAL ANALYSES.

Wyoming No. 5.

		Mine samples.		Car sample.
Laboratory No.		3164	3165	3213
Air-drying loss		4.00	4.40	6.00
Proximate:				
Moisture		12.41	13.10	11.64
Volatile matter		36.57	34.97	36.37
Fixed carbon		48.50	48.59	48.58
Ash		2.52	3.34	3.41
Sulphur		.80	1.04	.81
Ultimate:				
Hydrogen				5.72
Carbon				66.08
Nitrogen				1.43
Oxygen				22.55
Calorific value (as received):				
Determined	calories	6,622		6,538
	B. t. u.	11,920		11,768
Calculated from ultimate analysis	calories			6,357
	B. t. u.			11,443

PRODUCER-GAS TEST.

Wyoming No. 5 (run of mine).

Test 114.—Duration of test, 50 hours. Average electrical horsepower, 194.5. Average B. t. u. per cubic foot of gas, 168. Total coal fired, 15,600 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.72	1.52	1.46
Developed at switchboard	1.60	1.42	1.36
Per brake horsepower:			
Commercially available	1.46	1.29	1.24
Developed at engine	1.36	1.21	1.16

[a] For analysis of fuel used see p. 284 (sample 3363).

Analyses.

Coal.		*Gas by volume.*	
Moisture	11.44	Carbon dioxide (CO_2)	10.1
Volatile matter	36.37	Carbon monoxide (CO)	20.4
Fixed carbon	48.49	Hydrogen (H_2)	18.2
Ash	3.70	Methane (CH_4)	2.6
Sulphur	.91	Nitrogen (N_2)	48.3
		Ethylene (C_2H_4)	.4

COKING TEST.

Wyoming No. 5 (run of mine).

Test 132.—Size as used: Raw, finely crushed. Duration of test, 39 hours. Coal charged, 8,000 pounds. Coke produced, none. Analysis of coal: Moisture, 11.09; volatile matter, 34.53; fixed carbon, 50.5; ash, 3.88; sulphur, 0.84.

WYOMING NO. 6.

Subbituminous coal 3 miles west of Kemmerer, Uinta County, 2 miles from the Union Pacific Railroad, was designated Wyoming No. 6.

This sample, consisting of run-of-mine coal, loaded under the supervision of John W. Groves, was used in steaming tests 400 and (on briquets) 419, producer-gas test 124, and briquetting test 134.

Two mine samples were taken for chemical analysis. Sample 3202 was taken 150 feet north of the opening. Sample 3203 was taken 180 feet north of the drift opening. These two samples combined represent a thickness of 23 feet. The total thickness of the bed worked in this mine is 83 feet; consequently these two samples represent only a part of the entire bed.

CHEMICAL ANALYSES.

Wyoming No. 6.

		Mine samples.		Car sample.	Steaming tests.[a]	
					400.	419.
Laboratory No.		3202	3203	3390		
Air-drying loss		10.20	10.60	11.30		
Proximate:						
Moisture		20.57	20.88	19.00	18.44	15.57
Volatile matter		36.31	35.91	36.64	36.35	38.74
Fixed carbon		40.49	40.65	41.24	40.68	42.87
Ash		2.63	2.56	3.12	4.53	2.82
Sulphur		.51	.54	.49	.57	.59
Ultimate:						
Hydrogen				6.41	5.21	4.99
Carbon				59.38	71.93	74.59
Nitrogen				.98	1.19	1.03
Oxygen				29.62	15.42	15.35
Ash					5.55	3.34
Sulphur					.70	.70
Calorific value (as received):						
Determined	calories	5,687		5,726		
	B. t. u.	10,237		10,307		
Calculated from ultimate analysis	calories			5,743		
	B. t. u.			10,337		

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Wyoming No. 6 (run of mine.)

		Test 400.	Test 419.
Size as used:			
Over 1 inch	per cent	13.3	See p. 289
½ inch to 1 inch	do	25.5	
¼ to ½ inch	do	25.4	
Under ¼ inch	do	35.8	
Duration of test	hours	10.02	9.45
Heating value of fuel	B. t. u. per pound dry fuel	12,488	13,021
Force of draft:			
Under stack damper	inch water	0.62	0.56
Above fire	do	.33	.24
Furnace temperature	°F	2,465	.....
Dry fuel used per square foot of grate surface per hour	pounds	24.41	14.06
Equivalent water evaporated per square foot of water-heating surface per hour	pounds	3.32	1.99
Percentage of rated horsepower of boiler developed		93.1	55.7
Water apparently evaporated per pound of fuel as fired	pounds	4.76	5.13
Water evaporated from and at 212° F.:			
Per pound of fuel as fired	do	5.56	5.97
Per pound of dry fuel	do	6.82	7.07
Per pound of combustible	do	7.92	8.44
Efficiency of boiler, including grate	per cent	52.74	52.43
Fuel as fired:			
Per indicated horsepower hour	pounds	5.08	4.74
Per electrical horsepower hour	do	6.28	5.85
Dry fuel:			
Per indicated horsepower hour	do	4.15	4.00
Per electrical horsepower hour	do	5.12	4.94

Remarks.—Test 419 on briquets, which in burning gave a shower of sparks instead of a flame. For the first five hours too thick a fire was carried. With a 5-inch fire during the second five hours the briquets burned far better. No smoke. Briquets held together for about seven minutes, burning very slowly, and then crumbled. No clinker; ash fell through grate freely.

PRODUCER-GAS TEST.

Wyoming No. 6 (run of mine).

Test 124.—Duration of test, 50 hours. Average electrical horsepower, 200. Average B. t. u. per cubic foot of gas, 171.8. Total coal fired, 21,900 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	2.32	1.90	1.83
Developed at switchboard	2.19	1.79	1.73
Per brake horsepower:			
Commercially available	1.97	1.61	1.56
Developed at engine	1.86	1.52	1.47
Equivalent used by producer plant (pounds).			
Per electrical horsepower:			
Commercially available	2.52	2.06	1.99
Developed at switchboard	2.38	1.94	1.88
Per brake horsepower:			
Commercially available	2.14	1.75	1.69
Developed at engine	2.02	1.65	1.59

Analyses.

Coal.		*Gas by volume.*	
Moisture	18.26	Carbon dioxide (CO_2)	12.1
Volatile matter	37.18	Carbon monoxide (CO)	18.7
Fixed carbon	41.82	Hydrogen (H_2)	19.3
Ash	2.74	Methane (CH_4)	3.0
Sulphur	.47	Nitrogen (N_2)	46.5
		Ethylene (C_2H_4)	.4

BRIQUETTING TEST.

Wyoming No. 6 (run of mine).

Test 134.—Size as used: Over $\frac{1}{4}$ inch, 2.4 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 9.2 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 22.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 26 per cent; through $\frac{1}{40}$ inch, 40.2 per cent. Kind of binder, water-gas pitch; laboratory No. 3486 (see p. 40). Weight of fuel briquetted, 24,000 pounds. B. t. u. per pound of fuel as received, 10,106; per pound of briquets as fired, 10,994; per pound of binder, 16,407.

English briquets made at 179° F., average weight 3.18 pounds, with 5, 6, 7, 8, and 10 per cent of binder, would not cohere; all the briquets could be crushed in the hand. In the weathering test they were exposed 180 days; condition of those with 5 and 6 per cent binder, D; of those with 7 and 8 per cent binder, E.

Drop test.

Percentage of binder	5	6	7	8
Held by 1-inch screen	35.4	61.3	74	79
Passed 1-inch screen	64.6	38.7	26	21

Renfrow briquets made at 149° F., average weight 0.42 pound, with 7, 8, and 10 per cent binder, were not improved by increase in percentage of pitch; all briquets were bad and could be crushed in the hand. Weathering test, exposed 180 days, condition E. For analyses of briquets see page 287 (steaming test 419).

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 134.
Laboratory No.	3486	3390	.....
Air-drying loss ... per cent	.....	11.30	4.90
Extracted by CS_2:			
Air-dried ... do	.....	.94	6.12
As received ... do	85.57	.83	5.82
Pitch in briquets, as received ... do	.....	.....	6.13

MISCELLANEOUS TESTS.

MISCELLANEOUS COKE.

Fuel designated miscellaneous coke was used in producer-gas test 151.

PRODUCER-GAS TEST.

Miscellaneous coke.

Test 151.—Duration of test, 41 hours. Average electrical horsepower, 199.5. Average B. t. u. per cubic foot of gas, 120.6. Total coal fired, 8,400 pounds.

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower hour (pounds).			
Per electrical horsepower:			
Commercially available	1.03	0.95	0.83
Developed at switchboard	1.03	.95	.83
Per brake horsepower:			
Commercially available	.87	.80	.70
Developed at engine	.87	.80	.70

Analyses.

Coal.		*Gas by volume.*	
Moisture	7.86	Carbon dioxide (CO_2)	9.2
Volatile matter	.69	Carbon monoxide (CO)	21.9
Fixed carbon	79.94	Hydrogen (H_2)	11.1
Ash	11.51	Methane (CH_4)	0.2
Sulphur	1.14	Nitrogen (N_2)	57.5
		Ethylene (C_2H_4)	.1

MIXED COKE.

Fuel taken from a pile containing a mixture of the products of the coking tests was designated mixed coke. This sample was used in steaming test 519, to determine the effect of the absence of volatile matter in fuel on the completeness of combustion.

CHEMICAL ANALYSES.[a]

Mixed coke.

Proximate:		Ultimate:	
Moisture	6.55	Hydrogen	0.57
Volatile matter	.81	Carbon	81.34
Fixed carbon	79.78	Nitrogen	.89
Ash	12.86	Oxygen	2.40
Sulphur	.97	Ash	13.76
		Sulphur	1.04

STEAMING TEST.

Mixed coke.

		Test 519.
Duration of test	hours	8.92
Heating value of fuel	B. t. u. per pound dry fuel	12,366
Force of draft:		
Under stack damper	inch water	0.89
Above fire	do	.07
In ash pit	do	.25
Furnace temperature	°F	2,560
Dry fuel used per square foot of grate surface per hour	pounds	27.92
Equivalent water evaporated per square foot of water heating surface per hour	do	4.65
Percentage of rated horsepower of boiler developed		130.3
Water apparently evaporated per pound of fuel as fired	pounds	6.44
Water evaporated from and at 212° F.:		
Per pound of fuel as fired	do	7.80
Per pound of dry fuel	do	8.35
Per pound of combustible	do	10.00
Efficiency of boiler, including grate	per cent	65.21
Fuel as fired:		
Per indicated horsepower hour	pounds	3.63
Per electrical horsepower hour	do	4.48
Dry fuel:		
Per indicated horsepower hour	do	3.39
Per electrical horsepower hour	do	4.18

ILLINOIS, COLLINSVILLE.

Nut coal from Collinsville, Ill., was purchased, uninspected, by the Government for special steaming tests to determine the best method of firing Illinois coal, as follows: Test 500, alternate method of firing; test 501, spreading method; test 502, coking method; test 503, ribbon method (firing alternately in narrow strips across the full length of the grate); test 504, alternate method; and test 505, alternate

[a] Steaming test 519. Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from *car sample.*

method with forced draft. This fuel was also used in test 517 to determine the effect of reduced grate area on efficiency.

CHEMICAL ANALYSES.

Illinois, Collinsville.

	Steaming tests.[a]						
	500.	501.	502.	503.	504.	505.	517.
Proximate:							
Moisture	12.59	13.08	14.00	14.05	10.80	13.60	11.98
Volatile matter	35.94	35.34	33.85	33.64	36.76	35.17	35.11
Fixed carbon	42.34	42.62	42.43	41.37	42.81	41.51	43.83
Ash	9.13	8.94	9.70	10.94	9.63	9.72	9.08
Sulphur	3.24	3.16	3.36	3.35	3.31	3.22	2.85
Ultimate:							
Hydrogen	4.95	4.97	4.90	4.81	4.93	4.91	4.99
Carbon	70.33	70.51	69.48	68.30	70.03	69.65	70.81
Nitrogen	1.11	1.12	1.09	1.08	1.11	1.10	1.11
Oxygen	9.46	9.47	9.34	9.18	9.42	9.36	9.53
Ash	10.44	10.29	11.28	12.73	10.80	11.25	10.32
Sulphur	3.71	3.64	3.91	3.90	3.71	3.73	3.24

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

STEAMING TESTS.

Illinois, Collinsville (nut).

	Test 500.	Test 501.	Test 502.	Test 503.	Test 504.	Test 505.	Test 517.[a]
Duration of test ... hours	9.02	6.42	8.82	7.27	6.37	7.37	6.33
Method of firing	Alternate.	Spreading.	Coking.	Ribbon.	Alternate.	Alternate.	
Heating value of coal, B. t. u. per pound dry coal	12,586	12,823	12,649	12,434	12,739	12,670	12,861
Force of draft:							
Under stack damper ... inch water	0.93	0.64	0.85	0.91	0.91	0.99	0.50
Above fire ... do	.22	.16	.12	.14	.19	.13	.27
In ash pit (forced draft) ... do	.....	.....	.....	.....	.....	.25	.....
Furnace temperature ... °F	2,555	2,531	2,158	2,552	2,484	2,755	.....
Dry coal used per square foot of grate surface per hour ... pounds	25.10	22.17	21.87	24.49	24.17	30.36	28.77
Equivalent water evaporated per square foot of water-heating surface per hour, pounds	4.00	3.31	3.39	3.81	3.59	4.69	2.31
Percentage of rated horsepower of boiler developed	112.1	92.7	95.0	106.7	100.8	131.6	64.6
Water apparently evaporated per pound of coal as fired ... pounds	5.75	5.34	5.50	5.51	5.49	5.52	5.82
Water evaporated from and at 212° F.:							
Per pound of coal as fired ... pounds	6.98	6.49	6.67	6.69	6.64	6.69	7.06
Per pound of dry coal ... do	7.99	7.47	7.76	7.78	7.45	7.74	8.02
Per pound of combustible ... do	9.10	8.52	8.93	9.18	8.46	8.90	9.41
Efficiency of boiler, including grate. per cent	61.31	56.26	59.24	60.42	56.48	58.99	60.22
Coal as fired:							
Per indicated horsepower hour. pounds	4.05	4.36	4.24	4.23	4.26	4.23	4.01
Per electrical horsepower hour ... do	5.00	5.38	5.23	5.22	5.26	5.22	4.94
Dry coal:							
Per indicated horsepower hour ... do	3.54	3.79	3.64	3.63	3.80	3.65	3.53
Per electrical horsepower hour ... do	4.37	4.67	4.50	4.49	4.69	4.51	4.35

[a] Grate area reduced to 20.3 square feet.

WASHERY REFUSE.

Fuel taken from the dumping pile of the coal washery of the fuel-testing plant was designated washery refuse. This sample was composed of the dumpings of many bituminous coals and had been exposed several months before it was taken up for test. Steaming test 479 was made on it to determine whether such refuse can be used for steaming purposes.

CHEMICAL ANALYSES.[a]

Washery refuse.

Proximate:		Ultimate:	
Moisture	10.83	Hydrogen	2.83
Volatile matter	17.21	Carbon	39.81
Fixed carbon	30.14	Nitrogen	.68
Ash	41.82	Oxygen	7.09
Sulphur	2.40	Ash	46.90
		Sulphur	2.69

STEAMING TEST.

Washery refuse.

		Test 479.
Size as used:		
Over 1 inch	per cent	5.6
½ inch to 1 inch	do	13.8
¼ inch to ½ inch	do	16.6
Under ¼ inch	do	64.0
Average diameter	inch	.38
Duration of test	hours	7.18
Heating value of coal	B. t. u. per pound of dry coal	7,241
Force of draft:		
Under stack damper	inch water	.92
Above fire	do	.06
In ash pit (forced draft)	do	.73
Dry coal used per square foot of grate surface per hour	pounds	3,645
Equivalent water evaporated per square foot of water-heating surface per hour	do	2.59
Percentage of rated horsepower of boiler developed		72.6
Water apparently evaporated per pound of coal as fired	pounds	2.63
Water evaporated from and at 212° F.:		
Per pound of coal as fired	do	3.17
Per pound of dry coal	do	3.56
Per pound of combustible	do	8.06
Efficiency of boiler, including grate	per cent	47.48
Coal as fired:		
Per indicated horsepower hour	pounds	8.92
Per electrical horsepower hour	do	11.01
Dry coal:		
Per indicated horsepower hour	do	7.94
Per electrical horsepower hour	do	9.81

MISCELLANEOUS NO. 5.

A sample of coke breeze was furnished by a gas company for use in briquetting tests 152 and (mixed with Tennessee No. 4, p. 234) 150 and 151. One sample (No. 3386) was taken for chemical analysis.

CHEMICAL ANALYSES.

Miscellaneous No. 5 (coke breeze).

		Sample.	Briquetting test 152.[b]
Laboratory No.		3386	3385
Air-drying loss		8.80	.....
Moisture		10.72	5.01
Volatile matter		4.08	10.70
Fixed carbon		73.25	72.05
Ash		11.95	12.24
Sulphur		1.02	1.05
Calorific value determined (as received)	calories	6,131	.....
	B. t. u.	11,036	.....

[a] Steaming test 479. Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

[b] Proximate analysis of fuel as received; no ultimate analysis of briquets was made.

BRIQUETTING TEST.

Miscellaneous No. 5 (coke breeze).

Test 152.—Size as used: Over ¼ inch, 2.8 per cent; $\frac{1}{10}$ inch to ¼ inch, 11 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 21.2 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 30.4 per cent; through $\frac{1}{40}$ inch, 34.6 per cent. These briquets were very soft when warm, giving nearly 25 per cent breakage in falling from delivery belt of machine and in handling with coke forks. They could not be piled satisfactorily while warm. When cold, they had a rough, hard surface, with coating of brown from the dies, and broke without crumbling, giving a rough fracture surface.

Details of manufacture:		Drop test (1-inch screen):	
Machine used	Renf.	Held ... per cent	60.5
Temperature of briquets ... °F	149	Passed ... do	39.5
Binder—		Tumbler test (1-inch screen):	
Kind	w. g. k.	Held ... do	72.5
Laboratory No. (see p. 40)	3410	Passed (fines) ... do	27.5
Amount ... per cent	8	Fines through 10-mesh sieve ... do	90.0
Weight of—		Weathering test:	
Fuel briquetted ... pounds	20,000	Time exposed ... days	198
Briquets, average ... do	0.437	Condition	A.
Heat value per pound—		Water absorption:	
Fuel as received ... B. t. u.	11,036	In 15 days ... per cent	20.6
Fuel as fired ... do	12,119	Average for first 5 days ... do	2.64
Binder ... do	16,478	Specific gravity (apparent)	1.030

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 152.
Laboratory No	3410	3386	3385
Air-drying loss ... per cent	.....	8.70	3.10
Extracted by CS_2:			
Air dried ... do	.....	.65	6.96
As received ... do	79.98	.59	6.74
Pitch in briquets as received ... do	.....	.....	7.75

MISCELLANEOUS NO. 9.

The sample designated Miscellaneous No. 9 consisted of coke breeze which was shipped from a plant in Madison, Ill.

This sample was used in briquetting tests 247 [a] and 249; also mixed with Pennsylvania No. 18 in briquetting tests 238†, 239†, 240†, and 248. (See pp. 211–213.)

One car sample (No. 4763) was taken for chemical analysis.

CHEMICAL ANALYSES.

Miscellaneous No. 9 (coke breeze).

	Sample.	Briquetting tests 247, 249. [b]
Laboratory No	4763	4827
Air-drying loss	1.30	1.30
Moisture	1.95	2.61
Volatile matter	.89	10.71
Fixed carbon	75.50	58.55
Ash	21.66	28.13
Sulphur	.66	.98
Calorific value determined (as received) ... calories	6,039	5,514
Calorific value determined (as received) ... B. t. u.	10,870	9,925

[a] The briquets made in this test were used in a special cupola test; see p. 45.
[b] Proximate analysis of fuel as received; no ultimate analysis of briquets made.

BRIQUETTING TESTS.

Miscellaneous No. 9 (coke breeze).

Test 247.—Size as used: Over $\frac{1}{4}$ inch, 2.2 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 8 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 15 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 25.6 per cent; through $\frac{1}{40}$ inch, 49.2 per cent. Attempts to briquet coke breeze with unslacked lime as a binder were unsatisfactory. Briquets were made by the addition of pitch to the lime, and showed when warm characteristics similar to those of the briquets made in test 249. The cold briquets, however, were much harder and continued to increase in hardness for several weeks. The hardened briquets had a smooth outer surface and a rough, hard fracture surface, with firm edges.

Test 249.—Size as used: Over $\frac{1}{4}$ inch, 1.6 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 7.6 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 15.8 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 25.8 per cent; through $\frac{1}{40}$ inch, 49.2 per cent. The characteristics of these briquets are similar to those noted in the report of test 248 (p. 212). These briquets had a coating of bronze from the dies, which showed perceptibly the erosive effect of the coke. Satisfactory briquets were made with 8 per cent binder, and no increase in cohesion was observed by increasing this percentage.

	Test 247.[a]	Test 249.
Details of manufacture:		
Machine used	Renf.	Renf.
Temperature of briquets	176	158
Binder—		
Kind	([b])	w. g. p.
Laboratory No. (see p. 40)	4879	4879
Amount....per cent	8 each.	8
Weight of—		
Fuel briquetted, pounds	6,000	2,000
Briquets, average, pound	0.642	0.520
Heat value per pound—		
Fuel as received, B. t. u.	10,870	10,870
Fuel as fired..B. t. u.	9,925	.....
Binder.....do....	16,805	16,805
Drop test (1-inch screen):		
Held.....per cent	66.0	67.0
Passed.....do....	34.0	33.0
Tumbler test (1-inch screen):		
Held.....per cent	86.5	79.5
Passed (fines).....do....	13.5	20.5
Fines through 10-mesh sieve.....per cent	65.0	81.0
Water absorption:		
In 23 days.....per cent	.....	18.8
In 10 days.....do....	10.0	.....
Average for first—		
6 days. .....do....	1.50	.....
5 days.....do....	.....	2.60
Specific gravity (apparent)	1.287	1.178

[a] The briquets made in this test were used in a special cupola test; see p. 45.
[b] Water-gas pitch and unslacked lime, 8 per cent each.

Extraction analyses.

	Pitch.	Fuel.	Briquets, test 247.
Laboratory No.	4879	4763	4827
Air-drying loss, ...per cent	.....	1.30	1.30
Extracted by CS_2:			
Air dried.....do....	.....	.15	7.32
As received.....do....	94.50	.15	7.22
Pitch in briquets as received.....do....	.....	.....	7.50

MISCELLANEOUS NO. 10.

Coal designated Miscellaneous No. 10 was used in washing test 177.

WASHING TEST.

Miscellaneous No. 10 (slack).

Test 177.—Jig used, Stewart. Raw coal, 56,560 pounds. Washed coal, 40,160 pounds; 71 per cent. Refuse, 16,400 pounds; 29 per cent.

Analyses.

	Raw coal.	Washed coal.
Moisture	6.67	11.06
Volatile matter	31.61	.....
Fixed carbon	51.19	.....
Ash	10.53	6.38
Sulphur	1.55	1.30

INDEX.

A.

Page.

Abbreviations, explanation of..... 11
Adams, A. K., work of..... 12
Adler, Curt, work of..... 25
Alabama coals, data on..... 14
tests of..... 47–61
Analyses, making of..... 8
results of, index to..... 14–19
Argentina coal, data on..... 14
tests of..... 61–63
Arkansas coal, data on..... 14
tests of..... 63–76
Armstrong, C. L., work of..... 26
Augustine, C. E., work of..... 22
Austin, H. C., work of..... 26

B.

Barclay, D. A., work of..... 26
Barker, Perry, work of..... 22
Barnaby, J. C., work of..... 26
Belden, A. W., on coking tests..... 32–33
work of..... 34
Bird, F. W., work of..... 22
Birdsong, J. H., work of..... 21
Bituminous coal, producer-gas tests of, summary of..... 28
Black, J. K., work of..... 26
Boilers, absorption of heat by..... 24
See also Steaming tests.
Boilers used, proportions of..... 22
Borries, W. J. von, work of..... 12
Breckenridge, L. P., on steaming tests..... 22–24
Bridgeman, A. B., work of..... 26
Briquets, binders used in..... 39–41
description..... 38–39
tests of..... 41–45
Briquetting tests, account of..... 36–46
coals for, sampling and drying of..... 41
coals tested by..... 46
equipment of..... 36–38
objects of..... 8, 9
personnel of..... 36
results of, index to..... 14–19
Brown, D. I., work of..... 21
Burrell, G. A., work of..... 21
Burrows, J. S., work of..... 12
Burrows, J. S. *See* Parker and Burrows.

C.

Carroll, R. T., work of..... 12
Chapman, W. J., work of..... 36
Chemical laboratory, analytical methods of. 20–21
equipment of..... 20
personnel of..... 21
work of..... 20–21, 47

Page.

Coal, purchase of, for Government use..... 11
waste of, in mining..... 9, 10–11
Coke, cupola tests of..... 34–35
tests of..... 289–290
Coking tests, account of..... 32–33
coals tested by..... 32–33
future work in..... 33
objects of..... 8, 9, 10
results of, index to..... 14–19
Cooper, H. M., work of..... 26
Cupola tests of coke, account of..... 34–35
cokes tested by..... 35
equipment for..... 35
methods of..... 34–35
results of, index to..... 14–19
Cupola tests of briquets..... 45

D.

Darton, N. H., cooperation of..... 12
Delamater, G. R., on washing tests..... 29–31
work of..... 7, 29
Delano, L. A., work of..... 26
Denver, Colo., fuel-testing plant at..... 6, 33

E.

English briquetting machine, use of..... 36–39
Explosives, investigation of..... 11

F.

Fernald, R. H., on producer-gas tests..... 25–28
Field work, description of..... 12–19
Fletcher, C. J., work of..... 22
Florida peat, data on..... 14
tests of..... 27, 76–78
Fuels, tests of, by States..... 7
character of..... 7–9
Fuel-testing plant, authorization of work of 5–9
future work of..... 9
removals of..... 6
personnel of..... 7

G.

Galt, Ralph, work of..... 22, 36
Gases, analysis of..... 10
Gas-producer. *See* Producer gas.
Georgia coal, data on..... 14
tests of..... 78–79
Gilmore, C. A., work of..... 25
Goodwin, J. G., work of..... 26
Gould, J. H., work of..... 29
Green, C. H., work of..... 22
Grine, H. A., work of..... 26
Groves, J. W., work of..... 12

H.

Page.

Harris, W. J., jr., work of 26
Hempelmann, W. L., work of 26
Herrling, G. C., work of 26
Holmes, J. A., introduction by 5-11
Hopkins, L. C., work of 26
Howell, Spencer, work of 26
Howell, S. P., work of 26

I.

Illinois coals, data on 14-15
tests of 79-124, 290-291
Indiana coals, data on 15-16
tests of 125-146
Indian Territory coals, data on 16
tests of 146-152
Ireland, N. G., work of 34

K.

Kansas coals, data on 16
tests of 153-158
Kentucky coals, data on 16-17
tests of 159-164
Kreisinger, Henry, work of 22
Kuss, R. H., work of 22

L.

Laichinger, John, work of 25
Laird, J. A., work of 7,25
Lemmon, W. B., work of 25,26
Lignite, producer-gas tests of, summary of. 28
Lord, N. W., on work of chemical laboratory 20-21
Loye, B. W., work of 26

M.

McCalip, J. A., work of 21
Malcolmson, C. T., on briquetting tests 36-46
Maryland coals, data on 17
tests of 165-166
Massachusetts peat, test of 26
Mine inspection, work of 11
Mining, waste of coal in 9,10
Missouri coals, data on 17
tests of 167-174
Moldenke, Richard, on cupola tests of coke .. 34-35
work of 34
Montana coals, data on 17
tests of 174-177
Moore, Edward, work of 29

N.

New Mexico coals, data on 17
tests of 177-187
Nordensen, C. O., work of 25
Norfolk, Va., fuel-testing plant at 6,10

O.

Ohio coals, data on 17
tests of 187-193

P.

Pahmeyer, Fred, work of 22
Park, W. M., work of 22
Parker, E. W., work of 12

Page.

Parker, E. W., and Burrows, J. S., on field work 12-19
Peat, tests of 26-27
Pennsylvania coals, data on 17-18
tests of 193-224
Peshak, R. E., work of 25
Peters, J. W., work of 21
Pitch for binders, quality of 39-40
Pittsburg, chemical work at 10
Pope, G. S. work of 22
Post, R. H., work of 22
Private parties, mention of, prohibition of. 5
Producer-gas tests, account of 25-28
coals tested by 27
conditions of 26-27
equipment for 25
objects of 8,10
personnel of 25-26
results of 27-28
index to 14-19
summary of 28

Q.

Quam, J. P., work of 7,25

R.

Railroads, use of briquets by 9
Ray, W. T., work of 22
Renfrow briqueting machine, use of 36-39
Roy, F. V., work of 25
Ryder, G. E., work of 22,36

S.

St. Louis, fuel-testing plant at 6
Samples, designation of 12
list of 13-19
Smith, C. P., work of 25
Smith, D. F., work of 26
Smoke, prevention of 10
Somermeier, E. E., work of 21
Spitler, G. O., work of 21
Stanton, F. M., work of 21
Steaming tests, account of 22-24
coals tested by 23
equipment for 22
objects of 8
personnel of 22
results of 24
index to 14-19
Steamships, use of briquets by 9
Stone, Lauson, work of 26
Stowe, L. R., work of 22
Strasser, Robert, work of 36
Strong, R. M., work of 26
Suter, John, work of 25

T.

Technologic branch, organization and work of 7
Tennessee coals, data on 18
tests of 224-258
Texas coals, data on 18-19
tests of 258-261
Teza, Julian, work of 26
Toensfeldt, Kurt, work of 25
Tough, F. B., work of 12

U. Page.
Utah coals, data on..... 19
tests of..... 262-266

V.
Vickers, W. E., work of..... 32
Virginia coals, data on..... 19
tests of..... 267-272
Vocke, C. W., work of..... 36

W.
Washery refuse, tests of..... 291-295
Washing tests, account of..... 29-31
coals tested by..... 31
equipment of..... 29-30
explanation of..... 30-31
objects of..... 8,9
results of, index to..... 14-19
Washington coals, data on..... 19
tests of..... 272-277
Waters, E. C., work of..... 21
Way, K. M., work of..... 12,21
Weeks, H. W., work of..... 22
Weidmann, W. C., work of..... 26
Weidner, P. G., work of..... 26
Welks, L. S., work of..... 22
West Virginia coals, data on..... 19
tests of..... 277-284
Wick, J. D., work of..... 7,29
Willis, R. C., work of..... 21
Woodman, C. E., work of..... 22
Wright, C. L., work of..... 36
Wyoming coals, data on..... 19
tests of..... 284-289

O

Bulletin No. 333 Series Q, Fuels, 7

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

COAL-MINE ACCIDENTS: THEIR CAUSES AND PREVENTION

A PRELIMINARY STATISTICAL REPORT

BY

CLARENCE HALL AND WALTER O. SNELLING

WITH INTRODUCTION BY

JOSEPH A. HOLMES

IN CHARGE OF TECHNOLOGIC BRANCH

WASHINGTON

GOVERNMENT PRINTING OFFICE

1907

CONTENTS.

	Page.
Introduction, by Joseph A. Holmes	3
Statistics relating to accidents in coal mines	5
Fatal accidents in the United States	5
Number of men killed for each thousand employed	5
Increase in the United States	5
Decrease in European countries	6
Protective legislation	6
Belgium	6
Great Britain	7
Prussia	7
France	7
Comparative summary	8
Causes of mine accidents	8
Fatal accidents from falls of roof and coal	8
Fatal accidents from gas and dust explosions	10
Fatal accidents from other causes	11
Number of men killed for each million tons of coal produced	11
United States	11
European countries	12
Conclusions	13
Prevention of mine accidents	14
Safety lamps	14
Use of explosives	15
Storage of explosives	18
Shot firers	18
Materials used for tamping	19
Watered zones	19
Aid to the injured	19
Enforcement of regulations	20
Study of mining conditions	20
Acknowledgments	21

INTRODUCTION.

By JOSEPH A. HOLMES.

The general supervision of the work of the coal-mine inspectors in New Mexico and Indian Territory was transferred on June 10, 1907, by the Secretary of the Interior to the Geological Survey in a letter from which the following paragraphs are extracted:

> I have to request that from and including the 1st day of July, 1907, you will take up the practical administration of the act for the protection of the lives of miners in the Territories, approved March 3 1891, and the act amendatory thereof, approved July 1, 1902, and the supervision of the work of the coal-mine inspectors in New Mexico and the Indian Territory appointed pursuant to said statute, and those who may hereafter be appointed in such Territories in which the aggregate annual output is in excess of 1,000 tons of coal.
>
> In this connection it is suggested that the officers of the Geological Survey having the matter in charge should not only investigate the general mining conditions in the Territories, but also the nature and extent of the mine accidents, particularly those resulting from explosions, and report to the Department the results of such investigations. These reports should contain also suggestions as to how the mining conditions may be improved and accidents prevented, without undue hardship to the operators.

In a letter dated June 14, 1907, this supervision of the work of the coal-mine inspectors was placed by the Director of the Survey under the technologic branch of that organization. In endeavoring to carry out the suggestions of the Secretary relative to the improvement of the mining conditions and prevention of mine accidents in the coal mines of the Territories, a number of examinations of the more dangerous coal mines of the Indian Territory were made by Clarence Hall, Samuel Sanford, Rollin T. Chamberlin, and the expert in charge of the technologic branch. Other and more extended examinations of the coal mines of both Indian Territory (Oklahoma) and New Mexico have been planned. Meanwhile Mr. Hall and his associates have been investigating the nature, extent, causes, and results of a number of disastrous coal-mine explosions in several of the States. These studies have been carried on in connection with the general investigation of the waste and destruction of coal in mining operations.

In connection with all these investigations, and with a view to determining the practicability of preventing coal-mine explosions and improving mining conditions, a general inquiry was begun by Mr. Hall, with the assistance of Walter O. Snelling and under the

advice of Prof. Charles E. Munroe, concerning the nature and extent of such explosions and the methods employed in the United States or in foreign countries to prevent their occurrence.

In response to numerous requests for information on this subject, a brief summary of the results of these inquiries has been prepared for immediate publication as the present bulletin. Later bulletins will deal with other phases of this subject and also embody the results of the investigations of coal mining and coal-mine accidents in the Territories.

The figures given in this report indicate that during the year 1906 nearly 7,000 men were killed or injured in the coal mines of this country, and that the number of these accidents caused directly or indirectly by mine explosions has been steadily increasing. It is also indicated that this increase has been due in part to the lack of proper and enforceable mine regulations; in part to the lack of reliable information concerning the explosives used in mining, and the conditions under which they can be used safely in the presence of the gas and dust encountered in the mines; and in part to the fact that in the development of coal mining not only is the number of miners increasing, but many areas from which coal is being taken are either deeper or farther from the entrance, where good ventilation is more difficult and the dangerous accumulations of explosive gas more frequent.

The increase both in the number and in the seriousness of mine explosions in the United States during past years may be expected to continue unless, through investigations made in the United States such as have proved effective in other coal-producing countries, information can be obtained and published concerning the explosives used, the conditions under which they may be used safely in the presence of coal dust or gas, and the general conditions which make for health and safety in coal-mining operations. Such information, obtained through comprehensive and impartial investigations, may serve in this, as in other countries, as an intelligent basis both for legislative enactments and for agreements among persons associated with mining operations.

One after another of these terrible underground disasters awakens the sympathies of the nation and arouses an earnest desire that they may be entirely prevented. Experience in the deeper and more dangerous coal mines of Belgium and other countries not only indicates that these mine accidents may be reduced to less than one-third their present number in the United States, but also gives promise of results which in the future may at least approach complete prevention.

COAL-MINE ACCIDENTS: THEIR CAUSES AND PREVENTION—A PRELIMINARY STATISTICAL REPORT.

By CLARENCE HALL and WALTER O. SNELLING.

STATISTICS RELATING TO ACCIDENTS IN COAL MINES.

FATAL ACCIDENTS IN THE UNITED STATES.

In the coal mines of the United States in 1906, 6,861 men were killed or injured, the number killed being 2,061 and the number injured being 4,800.

The number of men killed in the coal mines of the United States for each year from 1890 is shown in the following table:

Number of men killed in the coal mines of the United States, 1890–1906.

1890	701	1900	1,493
1891	1,076	1901	1,594
1892	859	1902	1,828
1893	965	1903	1,794
1894	957	1904	1,999
1895	1,057	1905	2,097
1896	1,120	1906	2,061
1897	947		
1898	1,049	Total	22,840
1899	1,243		

The total number of men killed since 1889, as shown above, is 22,840. It will be noted that as many violent deaths have occurred in the coal mines of the United States during the last six years as during the preceding eleven years, the number of fatal accidents having practically doubled within that time.

NUMBER OF MEN KILLED FOR EACH THOUSAND EMPLOYED.

INCREASE IN THE UNITED STATES.

The great increase in the production of coal during the last decade, and the related increase in the number of men employed in the industry, may seem to account for the increase in the number of fatal accidents. But the following table, giving the number of men killed for each 1,000 employed, shows that the increase can not be accounted for in this way:

Number of men killed in the coal mines of the United States for each 1,000 men employed.

1895	2.67	1901	3.24
1896	2.79	1902	3.49
1897	2.34	1903	3.14
1898	2.59	1904	3.38
1899	2.98	1905	3.53
1900	3.24	1906	3.40

DECREASE IN EUROPEAN COUNTRIES.

PROTECTIVE LEGISLATION.

In all the European coal-producing countries the output of coal has increased greatly during the last ten years, but the number of deaths per 1,000 miners, instead of increasing as in this country, has undergone a marked and decided decrease. This decrease has been due to the effect of mining legislation in those countries for the safeguarding and protection of the lives of the workmen, and has been made possible by government action in establishing testing stations for the study of problems relative to safety in mining, including the use of explosives.

BELGIUM.

The decrease in Belgium is shown in the following table:

Number of men killed for each 1,000 men employed in the coal mines of Belgium for each decade since 1830.

1831–1840	3.19	1871–1880	2.36
1841–1850	3.18	1881–1890	1.99
1851–1860	3.28	1891–1900	1.39
1861–1870	2.60	1901–1906	1.02

It will be seen from the above table that the study of mining conditions in Belgium has resulted in a reduction of the death rate per 1,000 men employed to one-third of the ratio now existing in the United States. It seems certain that if a similar study of mining conditions were to be made in the United States and proper legislation could be secured to enforce the conditions found to be necessary for a better safeguarding of the lives of the miners, the death rate from mine accidents would be greatly reduced. The following table gives the death rate from accidents in the coal mines of Belgium in the years 1895–1906:

Number of lives lost in the coal mines of Belgium for each 1,000 men employed.

1895	1.40	1901	1.16
1896	1.16	1902	1.07
1897	1.03	1903	1.14
1898	1.04	1904	.93
1899	.97	1905	.91
1900	1.05	1906	.94

GREAT BRITAIN.

The number of men killed in the coal mines of Great Britain for each 1,000 men employed is shown for each year since 1890 in the following table:

Number of men killed in the coal mines of Great Britain for each 1,000 men employed.

1891	1.50	1899	1.26
1892	1.49	1900	1.30
1893	1.55	1901	1.36
1894	1.60	1902	1.24
1895	1.49	1903	1.27
1896	1.48	1904	1.24
1897	1.34	1905	1.35
1898	1.28	1906	1.29

PRUSSIA.

The number of men killed in the coal mines of Prussia for each 1,000 men employed is shown for a number of years in the following table:

Number of men killed in the coal mines of Prussia for each 1,000 men employed.

1861–1866	2.66	1897	2.35
1867–1880	2.94	1898	2.86
1881–1890	2.93	1899	2.31
1891	2.89	1900	2.25
1892	2.21	1901	2.34
1893	2.62	1902	1.99
1894	2.21	1903	1.92
1895	2.54	1904	1.80
1896	2.58		

FRANCE.

In France the number of lives lost per 1,000 men employed has been very low for a number of years, but since the publication of the last available report an explosion has occurred at the Courrieres mine in that country, causing the death of more than 1,000 miners, and this would materially affect the result of any tabulation. The number of lives lost per 1,000 men employed for each year for which statistics are available is as follows:

Number of lives lost in the coal mines of France for each 1,000 men employed.

1901	1.03
1902	.95
1903	.86
1904	.89
1905	.84

COMPARATIVE SUMMARY.

On comparing the average death rates from accidents in coal mines for each 1,000 men employed in different countries the full significance of the figures already given may be seen.

In the following table, giving the average ratio for the last period of five years for which statistics are at hand, the position of the United States may be compared with that of the principal European coal-producing countries:

Number of men killed for each 1,000 men employed—averages for five years.

France (1901–1905)	0.91
Belgium (1902–1906)	1.00
Great Britain (1902–1906)	1.28
Prussia (1900–1904)	2.06
United States (1902–1906)	3.39

Belgium maintains the most thoroughly equipped testing station in the world, and for a number of years has carried out extensive experiments to devise means to prevent accidents and to increase the safety of workers in the mines. The success of these experiments will be better realized when it is stated that at the beginning of the investigations the number of men killed each year for each 1,000 men employed was 3.2, or very nearly that now shown for the United States, while at present it is less than one-third of that number.

Great Britain and Germany also maintain testing stations, where every question relating to the testing of explosives, safety lamps, rescue devices, and all similar matters may be submitted to experimental studies. As the result of this foresight great reductions have been made in the number of accidents in the coal mines of those countries.

CAUSES OF MINE ACCIDENTS.

FATAL ACCIDENTS FROM FALLS OF ROOF AND COAL.

In 1906 the causes of the fatal and nonfatal accidents in the coal mines of the United States were as follows:

Coal-mine accidents in the United States, 1906.

Accidents due to	Killed.	Injured.
Gas and dust explosions	228	307
Powder explosions	80	215
Falls of roof and coal	1,008	1,863
Other causes	732	2,192

It will be noted that 50 per cent of all the fatal accidents and 39 per cent of all the nonfatal accidents were the result of falls of roof and coal, and that accordingly these are the most prolific source of

accidents in the coal mines of the United States. The following statement of deaths from this cause per 1,000 men employed shows how the United States compares with several of the foreign coal-producing countries in this regard:

Deaths from falls of roof and coal per 1,000 men employed.

Belgium	0.40
France	.47
Great Britain	.64
Germany	.92
United States	1.70

In all the countries mentioned, except the United States, the use of excessive charges of explosives is prohibited by law, and definite limits are set as to the amount of any explosive that may be used. Although these regulations were framed with the object of preventing gas explosions, it is believed that they have been of marked effect in preventing accidents from falls of roof and coal, as the very great disturbing and jarring effect exerted by the discharge of large amounts of explosives in a mine is believed to be one of the most important causes of falls of roof. The actual fall of the rock or coal may not occur at the time of firing the charge, but the heavy shots weaken the wall and roof and start cracks that impair the support of the rock, so that months after the blast, without warning, the roof or wall falls.

It is also to be noted that explosions of fire damp and coal dust have a similar effect in jarring and weakening the walls and roof, and in gassy regions, where small explosions of fire damp are of frequent occurrence, falls from this cause may make up a considerable percentage of the total number. But even in such regions the use of explosives and unsatisfactory forms of lamps is generally the indirect cause of the fall, for nearly all explosions of fire damp are caused by ignition from the shots used in breaking out the coal or from naked lights used by the miners.

In all foreign countries from which statistics are available restrictions in the maximum amount of explosives allowed to be used have not only increased the safety from explosions of gas, but have also materially diminished the loss of life from falls of roof.

The following table shows the number of deaths per 1,000 men from falls of roof and coal in France for each five-year period since 1870:

Number of men killed from falls of roof and coal in France for each 1,000 men employed.

1871–1875	1.26
1876–1880	.95
1881–1885	.88
1886–1890	.62
1891–1895	.59
1896–1900	.47

The steady decrease in the death rate from this cause is noteworthy, and is undoubtedly due largely to the greater stability of the sides and roof when free from the jarring and fissuring effect of large charges of explosives.

In Belgium, results similar to those obtained in France have followed the reduction of the allowed charges, as will be seen from the following table:

Number of men killed from falls of roof and coal in Belgium for each 1,000 men employed.

1851–1860	0.998
1861–1870	.898
1871–1880	.708
1881–1890	.661
1891–1900	.512
1901–1904	.406

In Great Britain and Germany the results are similar to those in France and Belgium, and thus the evidence on this subject is found to be consistent, and to point uniformly to the conclusions mentioned.

FATAL ACCIDENTS FROM GAS AND DUST EXPLOSIONS.

Gas and dust explosions form another important cause of mine accidents. In the United States during 1906 11 per cent of all the deaths in coal mines were due to such explosions.

In general, explosions of coal dust and fire damp are brought about either by ignition from explosives used in mining or from miners' lamps. Both of these causes have received careful study at the foreign testing stations, and the result of the legislation which has followed is well shown in Belgium, where gas is particularly prevalent in the mines, but where, through precautions resulting from the study of the conditions that favor explosions, loss of life from this cause has been reduced to a minimum. The following statement shows how successful the results in this direction have been:

Number of men killed from explosions of fire damp in Belgium for each 1,000 men employed.

1831–1840	0.965	1871–1880	0.487
1841–1850	.764	1881–1890	.364
1851–1860	.428	1891–1900	.208
1861–1870	.344	1901–1904	.039

From this statement it will be seen that the number of fatal accidents resulting from the explosion of fire damp have been so greatly reduced that the present death rate from this cause is but one-tenth of that of thirty years ago. This has been due to systematic testing of safety lamps, only those forms being allowed to be used which are capable of withstanding rapidly moving currents of fire damp under all conditions likely to be encountered in mines, and to thorough testing of all explosives to determine the amount of each which can be fired without danger of explosions of fire damp or coal dust.

FATAL ACCIDENTS FROM OTHER CAUSES.

Other causes of fatal accidents in coal mines, such as defective hoisting machinery, suffocation by carbon dioxide or poisonous gases, collision of coal cars, and many other causes of similar nature, are generally within the control of the State mine inspectors, and if a sufficient number of intelligent and capable inspectors are provided accidents of this character may be kept within very close limits without great difficulty.

NUMBER OF MEN KILLED FOR EACH MILLION TONS OF COAL PRODUCED.

UNITED STATES.

When the total number of fatal accidents in the coal mines of the United States is considered with reference to the number of tons of coal produced, it is seen that the number of men killed for each million tons of coal produced has not changed materially in the last fifteen years. The following table shows the number of men killed in the coal mines of the United States for each million long tons of coal produced in each year since 1890:

Number of men killed in the coal mines of the United States for each million tons of coal produced, by years.

1890	4.97	1899	5.49
1891	7.14	1900	6.20
1892	5.36	1901	6.08
1893	5.93	1902	6.79
1894	6.28	1903	5.62
1895	6.13	1904	6.24
1896	6.53	1905	5.97
1897	5.30	1906	5.57
1898	5.34		

Considered in periods, the average results obtained are as follows:

Number of men killed in the coal mines of the United States for each million tons of coal produced, by periods.

General average, 1890–1906	5.93
1890–1895	5.97
1896–1900	5.77
1901–1906	6.04

It is very doubtful whether natural conditions in any other country in the world are so favorable as in the United States for getting out coal with the minimum amount of danger to the workmen employed. The structural relationships in the principal coal districts of the United States are entirely favorable, and beds of 4, 5, and 6 feet in thickness, lying in nearly horizontal positions and providing almost

ideal conditions for mining, make up a greater proportion of the coal properties in active development than in any other coal-producing country.

The coal mines of the United States, considered as a whole, are not troubled by fire damp to any greater extent than the mines of most other countries. The abundance and cheapness of timber in this country in the past should also have been factors of considerable importance in reducing the number of accidents in mines, inasmuch as with abundant timber the use of sufficient props to support the roof and sides would not be prevented by the factor of cost.

But in spite of all the natural conditions tending to reduce the percentage of mine accidents in the United States to a low figure, the accidents during the last fifteen years show directly contrary results. Considered in regard to the number of deaths per 1,000 men employed, the United States, as has already been pointed out, occupies a less favorable position than any other of the coal-producing countries, more than three times as many men out of each 1,000 employed being killed as in some of the European countries that are much less favored in natural conditions. In regard to deaths per million tons of coal the United States not only occupies a position worse than that of most of the European countries, but is also showing an increase in the rate, whereas every other country is showing a decrease.

EUROPEAN COUNTRIES.

The following statement shows the figures for Great Britain:

Number of men killed in the coal mines of Great Britain for each million tons of coal produced.

1874-1883	7.42
1884-1893	5.65
1894-1903	4.70
1904	4.41
1905	4.64
1906	4.31

For France the figures are as follows:

Number of men killed in the coal mines of France for each million tons of coal produced.

1900	5.55
1901	5.21
1902	4.80
1903	4.20
1904	4.55
1905	4.17

For Belgium, which is troubled with fire damp to a greater extent than any other coal-producing country, the figures are not so good as

those just given for France; but even in Belgium better results have been obtained for the three years 1904–1906 than in the United States, as will be seen from the following table:

Number of men killed in the coal mines of Belgium for each million tons of coal produced.

1895	7.70
1896	6.39
1897	5.77
1898	7.78
1899	5.77
1900	5.96
1901	6.93
1902	6.29
1903	6.68
1904	5.66
1905	5.64
1906	4.96

Prussia shows less favorable results than the United States in regard to lives lost per million tons of coal, yet during the last ten years there has been an almost steady decrease in the number killed per million tons mined, and the number of lives lost per 1,000 men employed has also decreased from 2.54 to 1.80, showing that the high death rate based on amount of coal produced is largely due to the natural conditions existing in the coal mines of that country.

CONCLUSIONS.

It has already been stated that in no country in the world are the natural conditions so favorable for the safe extraction of coal as in the United States, and it has also been pointed out that in spite of this fact the number of lives lost per 1,000 men employed is far higher than in any other coal-producing country, and that the number of lives lost per million tons of coal produced is exceeded by only one other country. It now remains to be shown that unless energetic means are taken to counteract this prevailing tendency not only will the death rate in proportion to men employed and tons produced increase as it has done in the last few years, but it will increase at a much more rapid rate.

With the depletion of the thicker and more favorably mined seams of coal, thinner and less regular seams must be worked. This factor will undoubtedly be of the greatest importance within a comparatively few years, and the natural result would be to greatly increase the death rate. The rising price of timber will have the effect of decreasing the number of wooden props used in mining, and probably will increase the chance of accidents from falls of roof and coal. Another important factor in the mines of the United States is to be found in the nationality of the miners. Most of the men are foreign

born, a large proportion of them are unable to understand English freely, and a still larger number are unable to read or write that language. Some of them are inexperienced and do not take proper precautions either for their own safety or for the safety of others. This becomes a most serious menace unless they are restrained by carefully enforced regulations.

With the mining of the smaller beds of coal and the gradual development of properties worked with more difficulty, bringing the mining conditions in the United States more nearly to a position of equality with those abroad, a great increase in the number of accidents must be expected unless proper steps are taken to remedy the conditions that have brought about the present remarkably high death rate in the coal mines of the United States.

PREVENTION OF MINE ACCIDENTS.

The successful results which have attended efforts made in European coal-producing countries to reduce the dangers of coal mining have already been mentioned. The most important of the means through which these results have been achieved, in the opinion of the investigators who have had the matter in charge, will now be considered and some of the regulations governing coal-mine operations in foreign countries will be briefly discussed. No mention is made herein of many of the admirable precautions taken in some of the foreign mining districts for combating unfavorable local conditions, and many regulations, such as those in regard to timbering, spacing of pillars, and width of rooms and entries, will be taken up in a later paper.

SAFETY LAMPS.

The compulsory use of safety lamps in mines having a dangerous amount of fire damp is general in all the European coal-producing countries. The regulations on this subject for Great Britain are as follows:[a]

RULE 8. No lamp or light other than a locked safety lamp shall be allowed or used (*a*) in any place in a mine in which there is likely to be any such quantity of inflammable gas as to render the use of naked lights dangerous; or (*b*) in any working place approaching near a place in which there is likely to be an accumulation of inflammable gas.

And when it is necessary to work the coal in any part of a ventilating district with safety lamps, it shall not be allowable to work the coal with naked lights in another part of the same ventilating district, situated between the place where such lamps are being used and the return airway.

RULE 9. Whenever safety lamps are used, they shall be so constructed that they may be safely carried against the air current ordinarily prevailing in that part of the mine in which the lamps are for the time being in use, even though such current should be inflammable.

[a] Coal-mines regulation act, 1887, paragraph 49.

The laws of the other coal-producing countries are similar in essential particulars to those of Great Britain.

The keeping of at least two safety lamps in all mines (whether thought to be gaseous or not) is also required in some countries; and laws regulating the manner of locking safety lamps and requiring that all lamps shall be capable of being so locked by magnetic devices, compressed air, or other means, as not to be opened by any unauthorized person, are also in effect.

The employment of relighting stations, at which locked safety lamps may be relighted in the mine when they are accidentally extinguished, is permitted in several countries. In the coal-mines regulation act of Great Britain, rule 10, it is stated that relighting stations must not be in the return air from any part of the mine in which safety lamps are required to be used, the object of this provision being to prevent the possibility of fire damp being ignited at the relighting station and passing back to the workings. In Belgium and Germany the lamps in use are equipped with relighting devices of approved design, and are known to be practically free from danger of igniting fire damp, so that relighting stations are unnecessary.

Provisions regarding the examination of safety lamps at regular intervals by some competent person, to see that they are kept in safe condition, and regulations forbidding the possession by any unauthorized person of any contrivance for opening the lock of any safety lamp are also generally in force in France, Belgium, Germany, and Great Britain.

USE OF EXPLOSIVES.

The various commissions which have been appointed by Great Britain, France, Germany, and Belgium for the study of mining conditions have brought out the fact, thoroughly proved by experiment and by actual tests in mines, that certain types of explosives are much more liable than others to ignite fire damp and thus to cause gas explosions. This is true whether we consider (1) a test based on equal weights of the two explosives or (2) the fairer test of such weights of each as have equally powerful effects.

Accordingly, in all the European coal-producing countries, regulations have been made forbidding the use of such explosives as are known to be most dangerous in this respect, in all mines in which fire damp is liable to be present to a dangerous extent, and requiring the use in these mines of such explosives as have been proved to be reasonably free from the danger of igniting explosive-gas mixtures.

The order regulating the use of explosives in Great Britain contains the following provisions:

(*a*) In all coal mines in which inflammable gas has been found within the previous three months in such quantity as to be indicative of danger no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of

use into the seam or seams in which the gas has been found or any shaft or drift communicating therewith which is in process of being deepened or sunk, or being driven, as the case may be.

(*b*) In all coal mines which are not naturally wet throughout no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of use into any road or any dry and dusty part of the mine, or any shaft or drift communicating therewith, which is in process of being deepened or sunk, or being driven, as the case may be.

The "permitted explosives" to which reference is made are those explosives which have been found, after testing at the Government experiment station, to be capable of being fired in an explosive-gas mixture without causing the ignition of the gas. A "list of permitted explosives" is kept, including all those explosives that answer the required test, and all explosives used in mines that are dangerous because of gas or coal dust must be selected from this permitted list, which now includes more than fifty explosives.

Similar restrictions in the use of unsafe explosives were enforced in Great Britain in the coal-mines regulation act of 1887, and control of like kind is exercised in France, Belgium, and Germany. In all these countries the restriction of unsafe explosives has caused the development of "safety" explosives, which have proved greatly superior to those previously in use. The stimulating effect that the restriction of the more dangerous types of explosives has had on the invention and testing of safety explosives is well shown by the number of safety explosives devised each year. These explosives are as satisfactory in every respect as the common powder previously in use, and yet are free from most of the danger of causing mine explosions, inseparably connected with the use of the older explosives. Several of the newer explosives, for example, have been found to be incapable of igniting an explosive mixture of fire damp and air, even when the charge of the explosive is 700 grams; whereas as little as 30 grams of the older explosives would invariably cause an explosion of fire damp.

In Belgium, owing to the greater amount of fire damp present in the mines of that country, a further restriction, known as the charge limit, has also been put in force. Through this restriction the maximum amount of any explosive which is allowed to be used in any single charge is defined. The actual amount allowed varies according to the relative liability of the explosive to ignite fire damp, but with all the better class of explosives it is well above the amount needed for use in a single charge under proper mining conditions.

These restrictions in the kind and amount of explosives have yielded an additional benefit in the fact that the reduction in the amount used not only reduces the number of accidents, but also to a large degree prevents coal waste. The miner finds that with the restricted amount of explosive allowed it is necessary to mine by machine or hand in order that the explosive may produce the coal, and a larger per cent of lump coal is consequently produced. He also finds that the props

for supporting the roof can be set closer to the face of the workings, the smaller amount of explosive being less liable to knock them down. The miner in this manner secures greater protection through the increased support of the roof.

The importance of this work in regard to the prevention of accidents from explosives has been well summarized by V. Watteyne, chief engineer of the administration of mines, Belgium, as follows:

The use of explosives is, and especially was, the principal cause of danger of explosion in the mines. It is this cause which, previous to 1890, before the generalization of safety explosives and before the use of explosives of every description had been reduced by various means to a minimum, brought about deadly catastrophes. Within the decennial period 1880–1889 the number of victims of ignitions caused by the use of explosives reached 90 per cent of the total number of victims of explosions in mines.

It may be asked, What is the reason for such a preponderance, considering that the number of lights introduced into the mine by the lighting apparatus is far greater than the number of shots? It would be too long to examine here in detail the causes of the greatest danger of explosives, but we will mention the principal ones in a few words. On one hand the safety lamp, though still imperfect, has acquired a fair degree of safety; on the other hand, the flame of a lamp, even when uncovered, can not ignite a fire-damp mixture unless its proportion of fire damp be very high, say 6½ to 7 per cent, a proportion which the aspect of the flame betrays in a very apparent manner a long time before; nor can it ignite a mixture of dust. The case is different with the violent flames caused by the explosion of charges, for these are not only liable, by the shock they produce in the atmosphere of the workings, to call forth to the dangerous point an unexpected rush of fire damp, but they can ignite the clouds of dust which this very commotion has raised, and in this way can bring about terrible catastrophes, while in consequence of the apparent absence of fire damp one may think himself nearly safe.

The endeavors made after 1887, in consequence of disastrous explosions, to reduce the danger of explosives have brought about a very sensible reduction of the number of the victims of blasting. Thus within the following decennial period, from 1890 to 1899, in spite of the awful accident of Anderlues, which, in 1892, made 160 victims, the total number of men killed by mining explosions in Belgium has been reduced to 258, from the previous figure of 455, the proportions of victims of ignition by the use of explosives having fallen to 23 per cent.

In connection with the foregoing statement the following table will prove of interest, showing the remarkable increase in the use of safety powder in Belgium during ten years, coincident with the decrease in the use of black blasting powder for the same period.

Use of safety explosives and black blasting powder in the coal mines of Belgium.

Year.	Safety explosives.	Black powder.
	Kilograms.	*Kilograms.*
1895	80,786	689,344
1897	128,870	557,900
1899	176,440	465,648
1901	247,849	442,780
1903	399,821	415,292

It should be further noted that the black powder was restricted to mines not containing fire damp.

STORAGE OF EXPLOSIVES.

Regulations governing the storage of explosives for use in coal mines are in general effect in European coal-producing countries, and provide that no explosive substance shall be stored in the mine, that no explosive shall be taken into a mine except in canisters containing not more than 5 pounds, and that no unused powder shall be left in a mine over night. The amount of powder in the possession of a workman at any one time is also limited, and the amount which can be taken into a mine is usually restricted to that which will be used in one shift.

SHOT FIRERS.

Regulations enforced in Great Britain provide that in all mines in which inflammable gas is present or has been found in dangerous quantities within the previous three months all charges of explosives shall be fired by a competent person, termed a shot firer. The object is to place responsibility in the hands of men better qualified for the work than the average miner. The shot firer begins his work after the miners have left for the day, each miner before leaving having prepared a number of holes in such places as he wishes charges to be fired. The shot firer charges the holes with explosive and tamps and fires the charges.

It will be seen that by this method the charges are fired at a time when but few men are in the mine, and that accordingly, if a fire-damp explosion occurs, fewer lives are lost than if the miner fired the shots at a time when other miners were in the workings.

Still another factor of greater importance is that the shot firer, through constant experience, soon becomes used to the proper use of explosives, and also learns to charge the holes and fire them in the safest way possible. The shot firer is also free from the temptation to use excessive charges in the desire to get out a great amount of coal with the least possible effort. It is well known to all persons experienced in coal mining that overcharging of holes and mining by means of large shots fired in the solid mass of the coal bring about many fire-damp and coal-dust explosions.

At the present time several electrical shot-firing devices are being tested, with some promise of effecting a considerable saving of life. The main principle of these devices is the firing of the charges one after another at proper time intervals. As already stated, the firing of the charges takes place after the miners have left for the day, and the entire operation of the devices is automatic. It is of course necessary, after the charges are fired, to have some one examine each room in which a shot has been fired to see that conditions are normal, and that no feeders of gas have been ignited which might start a mine fire. The use of shot-firing devices or some other means equally safe is required *by regulation in* Great Britain.

MATERIALS USED FOR TAMPING.

The use of drill dust, slack coal, or other inflammable material for tamping is forbidden in European coal-producing countries, it having been found that gas and coal-dust explosions are more likely to occur when such materials are used. The laws of Great Britain compel the use of clay or like substance for tamping. The material is delivered to the miner near the working place.

WATERED ZONES.

The watering of the sides and roof of coal-mine passageways has been found to be of material benefit in preventing local ignitions of coal dust from becoming general. The watering prevents the coal dust from being stirred up by a small explosion, and the reduction in the explosive properties of the wet coal dust has the general effect of preventing an explosion from traveling into other workings. As dust explosions gain in destructive effect the farther they travel, it is believed that the thorough watering of zones greatly reduces the destructive effect of such explosions.

The watering is effected by means of sprinkling or spraying devices of various kinds. Specially constructed nozzles are in use, particularly in Germany, which produce a fine spray or mist by means of water under pressure, so that the air is thoroughly moistened.

An English commission has lately pointed out that sprinkling may produce a local weakening of the walls in some places, and the possibility of a slight increase in falls must accordingly be weighed against the advantages given by the protection from dust explosions.

AID TO THE INJURED.

The mining regulations of Germany, France, and Belgium require that mines shall be supplied with means for administering to the comfort of injured workmen and that proper appliances shall be provided for first aid.

Rescue devices equipped with small tanks of compressed air or compressed oxygen, or with some chemical appliance for generating a supply of oxygen, so as to enable a person to enter mine workings in which an irrespirable atmosphere is present, are required in some countries. By the aid of such apparatus rescue parties may enter the mine workings immediately after a fire-damp disaster and rescue injured miners, who would otherwise soon fall victims to the poisonous atmosphere surrounding them. Mine fires started by the ignition of feeders of fire damp may be brought under control much more easily when immediate efforts are made to combat them by men equipped with rescue devices.

ENFORCEMENT OF REGULATIONS.

In all European countries the enforcement of regulations in regard to coal-mine operations is placed in the hands of specially appointed officers or mine inspectors familiar with the industry and able to examine mining conditions intelligently and see that the mining laws are obeyed.

To insure compliance with the regulations, penalties are provided in case of noncompliance, and these penalties fall on the miner or the operator, or both, according to the nature of the violation. An injunction restraining the further operation of a mine until the laws have been obeyed is a further means in the hands of the mine inspector for insuring the enforcement of the law when the step is found necessary.

STUDY OF MINING CONDITIONS.

England, Germany, and Belgium maintain experiment stations where explosives are tested and where safety lamps, rescue appliances, and all other devices for use in mines may be examined. In France similar work is done by commissions which are appointed from time to time, and in other European countries there are permanent stations. It has already been pointed out in this paper that concurrently with the establishment of the experiment station, mine conditions begin to show the improvement that is so marked a feature of the statistics here presented. Safety lamps greatly superior to those previously in use were manufactured as soon as the defects of the earlier forms were pointed out at the experiment stations, and the development of improved forms of rescue appliances, electrical firing devices, and many other means of giving increased safety to mine workers have been inseparably connected with the stimulus given by these stations.

Inventors have been encouraged by the knowledge that the actual merits of any improvement they might make could be determined at the testing station, and at the same time mine owners have been able to see the results of thorough tests of all new devices, and to choose types of safety lamps, rescue appliances, and other devices, with a full knowledge of their working under actual mining conditions.

The experiments thus made have been of general benefit, and, aside from reducing the death rate from accidents in mines to a very low figure, they have been the means of bringing about improvements in operation that have been a substantial advantage to both mine workers and mine owners.

ACKNOWLEDGMENTS.

The statistics relating to mine accidents in the United States for the years 1905 and 1906 are taken from "The production of coal in 1906," by E. W. Parker, of the United States Geological Survey. The statistics relating to mine accidents in the United States for a number of years previous to 1905 are derived from tables prepared by F. L. Hoffman, of the Engineering and Mining Journal, and printed in the fifteenth annual report of the Tennessee mining department.

Acknowledgments are due to Mr. William Cameron, United States mine inspector for Indian Territory, Mr. Jo. E. Sheridan, United States mine inspector for New Mexico, and many other State mine inspectors, for numerous favors and suggestions received during the writers' visit to the mining districts under their supervision; also to Capt. J. H. Thompson, chief inspector of explosives of Great Britain, and to Mr. V. Watteyne, chief engineer of the administration of mines, Belgium, for many kind favors extended during the recent visit to foreign testing stations.

The statistics of mine accidents in Belgium are taken from "Annales des mines de Belgique" or from "Les lampes de sureté et les explosifs," by V. Watteyne. The figures stated for France are from "Statistique de l'industrie minérale en France et en Algérie." The statistics for Prussia are from the "Zeitschrift für das Berg-, Hütten-, und Salinen-Wesen im preussischen Staate." The statistics for Great Britain were taken from "General reports and statistics, mines and quarries." The tables relating to accidents from falls of rock and coal are mainly from "Der Verhandlungen und Untersuchungen der Preussischen Stein- und Kohlenfall Commission;" and some general statistics of mine accidents were also obtained from that work.

The general excellence of the European reports is especially noteworthy, and the complete and careful classifications adopted by them have greatly assisted in the preparation of this report.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 333.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports, Q, Fuels; R, Structural materials. This paper is the seventh in Series Q, the complete list of which follows (PP=Professional Paper; B=Bulletin):

SERIES Q, FUELS.

B 261. Preliminary report of the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp.

PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. 3 parts. 1,492 pp., 13 pls.

B 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp.

B 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

B 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., in 1904, 1905, and 1906, by L. P. Breckenridge, 1907. 196 pp.

B 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to July 1, 1907, J. A. Holmes, in charge. 1908. — pp.

B 333. Coal-mine accidents: Their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling. 1907. 21 pp.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

DECEMBER, 1907.

O

Bulletin No. 334 Series Q, Fuels, 8

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

THE BURNING OF COAL WITHOUT SMOKE IN BOILER PLANTS

A PRELIMINARY REPORT

BY

D. T. RANDALL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

CONTENTS.

	Page.
Introduction	5
General conditions in the United States	5
City ordinances for smoke prevention	7
The production of smoke	11
The prevention of smoke in boiler plants	12
Feasibility	12
The principles of smokeless combustion	12
Proper furnace equipment	14
Difficulty in securing perfect combustion	16
Indirect methods of smoke abatement	20
Summary	21
Bibliography	22

THE BURNING OF COAL WITHOUT SMOKE IN BOILER PLANTS.

By D. T. Randall.

INTRODUCTION.

The technologic branch of the United States Geological Survey has been conducting investigations to determine the best method of utilizing the coals of the United States. The law under which this work has been carried on aims to increase the efficiency and to prevent the waste of these fuels, especially such as are used by the United States Government. It is a recognized fact that the more nearly perfect the combustion of any fuel the greater is its efficiency. With perfect combustion there is no smoke. In view of the need for more complete information on the conditions favorable to the burning of coal with economy and without objectionable smoke in boiler furnaces, extended tests have been made at the fuel-testing plants at St. Louis, Mo., and Norfolk, Va. The results of the St. Louis tests are summarized in the present paper, which has been prepared by the author as engineer in charge of smoke-abatement investigations. In addition to this work a number of commercial plants in the larger cities have been inspected to ascertain what are the best methods now in use, and the information thus obtained will be published in a later bulletin.

GENERAL CONDITIONS IN THE UNITED STATES.

The prevention of objectionable smoke in the manufacturing and business centers of large cities is a problem that can not be easily solved. At present no city in which a considerable quantity of bituminous coal is burned is free from smoke. The cities of the East have avoided this problem by a general use of the smaller sizes of anthracite coal. For this reason it is not surprising that the greatest improvement in the methods of burning bituminous coal has been made in the Central and Western States.

Stoves, ranges, house-heating boilers, and hot-air furnaces are as a rule intended for the use of anthracite coal or coke. Whenever bituminous coal is burned in such furnaces all the principles of combustion are violated and smoke results. The supply of anthracite coal is limited, and except for domestic purposes such coal is little used outside of the territory adjacent to the mines. The larger cities of the Eastern States, which consume practically all the available supply of the smaller sizes of anthracite coal for power and heating purposes, now find it necessary to supplement this fuel with a considerable tonnage of bituminous coal. Except the power generated by waterfalls, nearly all the heat and power used in the United States are obtained from the burning of coal. It is evident, then, that for the most part this country must depend on its bituminous coal for manufacturing, railroad, and power-plant purposes. This means that we must improve our usual methods of burning bituminous coal or continue to suffer from the loss in economy and smoke resulting from imperfect combustion.

There are now three general methods of utilizing coal—in steam boiler and other furnaces, in gas-producer plants, and in by-product coke plants. Of these, the last two methods are readily operated to produce heat or power without smoke, but at the present time such plants are not numerous and consume only a small portion of the coal that is used in this country. It is predicted by persons who are enthusiastic regarding the economy and smokelessness of these methods that they will in time be used exclusively for the production of heat and power in all our large cities.

It has been demonstrated at the fuel-testing plants of the Geological Survey that bituminous coal of all grades can be burned in a gas producer without smoke, generating a gas which when used in a gas engine furnishes power with much greater economy than is usual in steam plants. With good grades of coal mined in the Eastern States a horsepower can be generated with about 1 pound of coal. One of the most important facts in connection with the gas-producer plant is that, besides being smokeless, it will utilize coals so high in ash as to be unsuitable for boiler furnaces. The lignite coals of the West are also particularly well adapted for use in the producer, though they are considered much inferior to bituminous coal for boiler furnaces. About fifty producer plants are now in operation in the United States, burning bituminous coal. Interest in such plants is increasing, and many new ones are being planned, ranging in capacity from 500 to 10,000 horsepower each.

That the coal supply is being wasted in many ways is a fact that has been frequently brought to the attention of the public. One waste results from the ordinary methods of manufacturing coke, in which *all of the gas* from the coal is allowed to escape into the air. This

loss has led to the installation of a few by-product coke plants in which coke is made and the resulting gas is piped to points where fuel is needed and there consumed. Other valuable products from the distillation of coal are also obtained. These plants, furnishing both coke and gas as fuel, constitute a considerable factor in the prevention of smoke in the cities near which they are located, as both fuels are burned readily without smoke for domestic purposes and for manufacturing industries requiring heat or power. The convenience and cleanliness of these fuels will probably lead to an increase of their production and use.

It is reported that there are 30 by-product coke plants in this country, with a total of more than 3,000 ovens, using nearly 20,000 tons of coal a day. It is estimated that these plants manufacture daily more than 50,000,000 cubic feet of gas. The following are some of the cities near which they are located: Chicago and Joliet, Ill.; Milwaukee, Wis.; Duluth, Minn.; Detroit and Wyandotte, Mich.; Ensley and Tuscaloosa, Ala.; Chester, Dunbar, Everett, Lebanon, Sharon, and Steelton, Pa.; Wheeling, W. Va.; Buffalo, Geneva, and Syracuse, N. Y.; Cleveland and Hamilton, Ohio.

In many manufacturing plants furnaces that were formerly fired with coal are now using crude oil, natural or manufactured gas, coke, or coal burned on automatic stokers. All these methods are giving good results in preventing smoke.

CITY ORDINANCES FOR SMOKE PREVENTION.

With the knowledge that it can be prevented, there has come an increasing demand from the people of the large cities that smoke shall not be allowed to pollute the atmosphere. This is true not only of the United States, but also of most European countries. For example, the importance of burning bituminous coal economically and without smoke led the Prussian government some time ago to furnish traveling instructors at an expense of about $10,000 a year for the training of firemen throughout the State, licenses being given to competent firemen. There are also in Prussia a number of boiler-supervision societies, which employ skilled firemen to direct the work done by the regular employees of the plants owned by members of the society.

In nearly all cities of the United States efforts are being made to abate the smoke given off by manufacturing, steam-boiler, and domestic furnaces in which bituminous coal is burned. As a result of the demands of the public the ordinances of some of these cities require that all new plants be equipped properly and that old ones be remodeled, and permits are now necessary for the installation of all boilers and furnaces. Most ordinances define the degree of black-

ness of smoke which constitutes a violation of the law. In general, it may be said that in this country the only excuse recognized for black or dense gray smoke is that the fires are being built or cleaned, but no such excuse is valid in many of our cities. The conditions in a number of the larger cities of the United States are about as follows:

The Baltimore ordinance contains a clause which practically excepts the manufacturing plants of the city. Cases brought into court were dismissed on account of defects in the ordinance, and an attempt is being made by the smoke-abatement league to secure the enactment of one that will be more effective. There are on record about 660 steam plants in Baltimore, not including heating plants. Of this number only 12 are equipped with automatic stokers.

The Buffalo ordinance is not effective, as it simply declares the emission of large quantities of smoke to be unlawful. In addition to the work of the smoke inspector, active efforts to improve the conditions have been made by the Society for Beautifying Buffalo.

The Chicago ordinance makes it unlawful to permit dense smoke to escape from any furnace except for six minutes of each hour during the time when fires are being started or cleaned. Members of the City Club of Chicago have taken an active interest in the suppression of smoke. There has recently been a reorganization in the smoke inspector's office and a committee of engineers has been appointed to assist and advise with that official. The following is a partial list of the equipment installed in Chicago: Plants with chain-grate stokers, 70; with overfeed stokers, 40; with underfeed stokers, 12; with special hand-fired furnaces, 40. In addition to these there are many small plants equipped with steam jets and other appliances.

The Cincinnati ordinance establishes a standard for density of smoke permitted and allows a period not exceeding six minutes in any hour during which the fires are started. During the past year citizens of Cincinnati have formed a smoke-abatement league and by public subscription raised a fund to pay the salary of a smoke inspector working under the league's direction. The city smoke inspector's office has been reorganized and a number of suits regarding fines for allowing stacks to smoke are pending in the courts. Action on other plants has been withheld until these cases are settled. The furnace equipment in Cincinnati is as follows: Down-draft furnaces, 90; other furnaces, 5; inclined-grate stokers (*a*) side feed, 113; (*b*) front feed, 56; (*c*) underfeed, 89; automatic steam jets, hand fired, 48; steam jets, not automatic, hand fired, 247.

The Cleveland ordinance excepts private residences, but dense gray or dense black smoke from other furnaces is declared to be in violation of the law. According to the records of the smoke inspector's office there are about 1,800 boilers in the city, equipped as follows:

Furnace equipment in Cleveland.

	Boilers.	Plants.
Chain-grate stokers	200	40
Inclined-grate stokers	400	164
Underfeed stokers	170	34
Down-draft furnaces	50	.....
Automatic steam jets	400	131
Nonautomatic steam jets	125	110
Miscellaneous devices, Dutch ovens, etc	.....	50
Smokeless coal used under	500	.....

The Detroit ordinance makes it unlawful to allow dense gray or black smoke to escape from any chimney. The smoke inspector is assisted by a committee of the chamber of commerce, and good results are being obtained. It is reported that in 1906 the following new equipment was installed: Mechanical stokers, 108; automatic smoke-prevention devices, 12; steam jets, 16.

The Indianapolis ordinance makes the production of dense gray or black smoke subject to a penalty, private residences being exempt. The efforts toward smoke abatement in this city are confined to the office of the smoke inspector. According to that official's report for the year ending December 31, 1906, the following equipment was in use:

Furnace equipment in Indianapolis.

	Boilers.	Plants.
Underfeed stokers	43	10
Inclined-grate stokers	100	18
Traveling-grate stokers	48	10
Down-draft furnaces	5	.....
Smokeless furnaces, brick-arch construction	15	.....
Automatic steam jets	65	.....
Total number of boilers in operation, reported	828	.....

At present there is no effective ordinance in Louisville and no smoke inspector. A movement has been started by a number of citizens to form a smoke-abatement league for the purpose of securing the passage of an ordinance and the organization of a smoke-inspection department. Last year there were in this city, in addition to the hand-fired plants, 13 plants with down-draft furnaces, 11 with chain-grate stokers, 18 with inclined-grate stokers, and 4 with underfeed stokers.

Milwaukee has an effective ordinance and the smoke-inspection department is doing a considerable amount of educational work among the manufacturers. The inspector reports that during 1905 the following installations were made: Underfeed stokers, 32; chain-grate stokers, 2; inclined-grate stokers, 15; down-draft furnaces, 6; automatic steam jets, 44; total, 99.

The ordinance of New York City makes no exception and provides a penalty for the emission of dense black smoke from any furnace. The smoke-abatement committee has been active in bringing of-

fenders against the law into court, and a number of power plants are installing additional equipment to comply with the smoke ordinance. In this city 12,200 stationary boilers are on record, but there is no record of the furnaces and equipment. It is reported, however, that there are 26 plants equipped with stokers of the overfeed type and 2 with stokers of the underfeed type. Many of these stoker plants are exceptionally large.

The Philadelphia ordinance declares the emission of smoke of greater density that the established standard unlawful, except from locomotives or steam craft standing with banked fires, or during a period of ten consecutive minutes when fires may be in process of being cleaned or started. Exception is also made of river craft in continuous transit through the city. The smoke-inspection department is assisted by the efforts of the citizens' committee, which has been active in creating a public sentiment in favor of smoke abatement. The number of boilers in the entire city, as reported by the chief inspector, is 8,194, of which 2,132 are using soft coal. The number of stokers and appliances for abating smoke is 220.

The Pittsburg ordinance declares that the production of dense black or dense gray smoke, except from private residences, is unlawful, but while a new fire is being started or the fires are being cleaned such smoke is allowed for a period of eight minutes in any hour.

The St. Louis ordinance provides a penalty for allowing dense smoke to escape into the air. According to this ordinance it is a good defense if the person charged with the violation shall show to the satisfaction of the jury or of the court that there is no practicable device, appliance, means, or method by which the emission of dense smoke could have been prevented. St. Louis has, in addition to its smoke-inspection department, a smoke-abatement committee maintained by the Civic League. According to the report of the smoke inspector for 1906, there were in the city plants with the following furnace equipment: Steam jets, 550 plants; down-draft furnaces, 264 plants; fire-brick arches, etc., 50 plants; automatic stokers, 19 plants.

An ordinance has recently been passed in Toledo, and the smoke inspector is making an effort to cooperate with the owners of plants in the suppression of smoke. The ordinance makes an exception of private residences, dense gray or black smoke from all other furnaces being a violation of the law.

The law governing the abatement of smoke in Washington and the District of Columbia makes an exception of private residences, but provides a penalty for dense gray or black smoke from all other sources. The law is rigidly enforced and there is but little smoke from bituminous coal.

THE PRODUCTION OF SMOKE.

The term smoke as used in this paper refers to chimney gases that contain small particles of unconsumed carbon, which give the gases a dark color. Smoke may be of any degree of blackness, but what some persons would call smoke is not considered smoke by others.

Smoke is due to a lack of air at the proper temperature at the point where the volatile gases should be burned, the result being that these gases are only partly burned and the carbon is set free. The density of smoke is measured in many ways, but the most satisfactory at present is by means of the Ringelmann charts. These charts are made by drawing black lines at right angles on a white background. The lines are so spaced as to give the effect of different percentages of blackness when placed at a distance of about 50 feet from the observer. The charts are numbered 1, 2, 3, 4, and 5, and represent, respectively, 20, 40, 60, 80, and 100 per cent of black smoke. As a matter of fact, anything but a clean stack will result in a smoky atmosphere. If a stack continuously emits a small amount of smoke, it may, during the course of the day, have given off as much carbon and have had as bad an effect as another stack which has been clear most of the time, but which for three or four periods of five minutes each has emitted a dense black smoke. In localities where bituminous coal is burned exclusively a plant is considered good if the average blackness is equivalent to 5 per cent or less.

The following information, taken from the report of the committee for testing smoke-preventing appliances, Manchester, England (see p. 24), is of interest:

Observations were made for an entire day on 179 chimneys. The general averages of these stacks gave the equivalent of black smoke 102 minutes in 10 hours. The averages for the individual stack varied from the equivalent of black smoke for 423 minutes in the worst to 4 minutes in the best. The relative amount of the smoke from different kinds of equipment may be taken as follows:

Average of 36 hand fires with air admission, 81 minutes in 10 hours; average of 10 hand fires with air admission, good firing, 40 minutes; average of 4 sprinkling stokers, about 103 minutes in 10 hours; average of 21 coking stokers, about 16 minutes in 10 hours; best coking stokers, about 4 minutes in 10 hours.

Coking stokers show best economy as well as prevention of smoke.

Sheffield Association suggest that the permissible limit of smoke emission should vary with the number of boilers as follows: For 1 boiler, 2 minutes per hour; for 2 boilers, 3 minutes per hour; for 3 or more boilers, 4 minutes per hour.

The following are reasons why furnaces sometimes smoke:

1. The furnaces and the grates are not properly designed to burn the coal available. There is almost no equipment on the market that will handle equally well all the fuels found in the United States.
2. There is a lack of sufficient draft.
3. The firemen are unskilled.

4. There is not enough combustion space.
5. Wood, paper, and other refuse are burned.
6. The load is changed quickly.
7. Excessive overloads are maintained.

THE PREVENTION OF SMOKE IN BOILER PLANTS.

FEASIBILITY.

Within the last few years there has been a remarkable development in the utilization of coal under the steam boiler. To-day many steam power plants in the United States are burning bituminous coal practically without smoke. This has been brought about by improving the design of the furnaces and by careful attention on the part of the fireman.

It is now possible to design and operate boiler plants burning a high-volatile coal which will be practically smokeless under usual operating conditions, giving off no black or dense gray smoke except when a fresh fire is being built. Banking the fire, shutting dampers, etc., causes smoke of a light or gray shade only. This has been demonstrated at the engineering experiment station of the University of Illinois, where a boiler has recently been installed, properly equipped with a furnace for burning Illinois coal. Under ordinary conditions this plant makes no smoke whatever. This equipment is not suitable for burning low-volatile coals such as are largely used in the East. In experimenting with this furnace an effort was made to produce smoke, but it was found impossible to make black smoke, the worst being about 50 per cent black.

A number of large commercial plants having properly designed furnaces are now operating daily without smoke in many of our larger cities. Reports on some of these plants inspected by engineers connected with the technologic branch will be published in a subsequent bulletin.

THE PRINCIPLES OF SMOKELESS COMBUSTION.

Coal can be burned smokelessly, the same as gas, gasoline, or kerosene oil, if the equipment is properly designed and adjusted. Each of these fuels will give off smoke if conditions are not favorable. All the authorities on the subject of combustion and smoke prevention agree upon the following conditions as requirements for a smokeless furnace:

1. The coal should be supplied to the furnace in small quantities at frequent intervals. The more nearly the feed approaches a continuous and uniform supply the better the results.

2. The air supply should be slightly in excess of the theoretical amount required and be admitted principally through the fuel bed, with an auxiliary supply admitted at the front or rear of the furnace to burn gases from the coal.

3. The temperature in the furnace should be sufficiently high to ignite the gases given off from the fuel bed.

4. There should be a fire-brick combustion chamber of sufficient dimensions and so designed as to cause the thorough mixture of the gases and air, permitting complete combustion before the mixture reaches the boiler surfaces.

Much has already been written on the theory and chemistry of combustion. "Steam-boiler economy," by William Kent, and "Steam boilers," by Peabody and Miller, are both good works on this subject. (See p. 23.)

It has been found in this country, as well as in Europe, that when smoke is given off, there is also a loss of carbon monoxide (CO) and other combustible gases. The loss due to the carbon which we see and call smoke is seldom more than 1 per cent, but the loss due to the escape of the combustible gases may amount to an additional 3 to 10 per cent.

The steam-engineering section of the technologic branch has found, as have other investigators, that, contrary to general opinion, with extremely high temperatures more smoke is produced and more unburned gases are lost up the stack. High temperature is of course due to a supply of air approaching the theoretical amount, and on account of the difficulty of obtaining a complete mixture of the gases and air some gas is allowed to escape unburned. (See Table 1.)

The combustible gas most frequently found in the flue gases is carbon monoxide (CO). This gas is nearly always present when the stack gives off black smoke, indicating imperfect combustion. Hydrogen and hydrocarbon gases may also be expected in connection with the CO, but on account of the difficulty of determining the small percentages of these gases they are seldom recorded, though the loss due to their escape is considerable. In confirmation of these statements, the accompanying tables are submitted. Table 1 gives a summary of the relation of smoke to unburned gases and combustion-chamber temperatures as determined from more than 200 boiler tests made at the St. Louis fuel-testing plant.

TABLE 1.—*Relation of smoke to CO and combustion-chamber temperatures.*

	Per cent of black smoke.						
	0.	0 to 10.	10 to 20.	20 to 30.	30 to 40.	40 to 50.	50 to 60.
Number of tests	37	18	56	51	36	17	4
Average per cent of smoke	0	7.1	15.5	24.7	34.7	43.1	52.9
Average per cent of CO in flue gases	0.05	0.11	0.11	0.14	0.21	0.33	0.35
Average per cent unaccounted for in heat balance	9.14	10.60	9.46	10.93	11.41	13.41	13.34
Number of tests[a]	26	16	48	45	32	17	4
Average combustion-chamber temperature (°F.)	2,180	2,215	2,357	2,415	2,450	2,465	2,617

[a] Temperatures in combustion chamber were not determined on all tests.

Table 2, from the Manchester report (see p. 24), gives analyses of chimney gases, including determinations of hydrogen (H) and methane (CH_4), which occur in small percentages.

TABLE 2.—*Analyses of chimney gases.*

Boiler.	Smoky.						Clear.					
	CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.	CO_2.	O_2.	CO.	CH_4.	H_2.	N_2.
No. 1, hand fired	11.00 10.65	6.90 6.45	0.90 2.15	.....	.....	81.20 80.75	.....	.....	.....	.....	.....	.....
No. 1, with smoke-prevention device	.....	.....	.....	.....	.....	.....	7.00 9.00	13.50 9.75	0 0	.....	.....	79.50 81.25
No. 2, hand fired	10.25	8.60	.50	0	0	80.65	.....	.....	.....	.....	.....	.....
No. 3, hand fired	13.25	3.50	.05	0.25	0	82.95	.....	.....	.....	.....	.....	.....
No. 4, fire under caustic pot, hand fired	10.95	1.30	3.00	.70	3.23	80.82	.....	.....	.....	.....	.....	.....
No. 5, split bridge, hand fired	8.75	7.00	3.25	.40	1.00	79.60	.....	.....	.....	.....	.....	.....
No. 6, with smoke-prevention device	.....	.....	.....	.....	.....	.....	7.25	12.00	0	0	0	80.75
No. 7, with smoke-prevention device	.....	.....	.....	.....	.....	.....	7.15	12.15	0	0	0	80.70
No. 8, with smoke-prevention device	.....	.....	.....	.....	.....	.....	8.15	11.10	0	0	0	80.75

Table 3, compiled from results obtained at the fuel-testing plant, shows that the losses due to the escape of CO and other combustible gases may be considerable and that they are of more importance than the gain from a corresponding increase in carbon dioxide (CO_2). It is evident that the prevention of smoke and the efficiency of the plant are very closely related.

Calculations showing the theoretical losses due to the presence of combustible gases in the flue gases have been made and the results published in "A study of four hundred steaming tests."[a]

TABLE 3.—*Relation of CO to efficiency.*

Number of tests.	15	11	29	25	21	28	42	32	34	49	7
Average per cent of CO_2 in flue gases	7.69	9.46	9.29	9.09	9.48	9.48	9.90	9.60	9.57	10.22	10.94
Average per cent of CO in flue gases	.63	.53	.27	.22	.17	.19	.13	.16	.12	.15	.10
Average efficiency (72*)[a]	52.96	56.73	59.56	62.08	63.43	64.58	65.55	66.41	67.48	69.10	71.73

[a] For discussion of efficiency 72* see A study of four hundred steaming tests: Bull. U. S. Geol. Survey No. 325, 1907.

PROPER FURNACE EQUIPMENT.

Numerous inventions for preventing smoke have been made, based, according to the inventors, on the recognized principles discussed in the foregoing section. Most of them have not been properly designed to meet the severe service to which a boiler furnace is subjected.

[a] Bull. U. S. Geol. Survey No. 325, 1907, pp. 100-101.

The proper design of the furnace and settings, including the breeching and stacks, is a subject of much dispute. All authorities, however, agree that sufficient air must be admitted to allow complete combustion. This means that ample draft must be provided. Stacks less than 125 feet high are usually unsatisfactory, but steam or electrically driven fans are now very commonly used to produce either forced or induced draft in connection with stacks shorter than would otherwise be required.

Provision should be made for the admission of air above the fuel bed. It is also now generally conceded that there should be a fire-brick chamber of sufficient length to allow time for the gases and air to mix and burn. Numerous observations made on power plants show that it takes an average of twelve seconds for the gases to pass from the furnace to the top of a stack 125 feet high. This allows but one second for combustion to take place before the gases leave the combustion chamber. These conditions have been so successfully met in some plants as to permit the use of low-grade coal without the production of objectionable smoke. These plants are few when compared to the total number in operation, but they indicate the possibilities of securing practically perfect combustion.

In general, furnaces designed for burning coal may be divided into two general classes, as follows:

I. Those into which coal is shoveled at intervals by hand:

(*a*) Plain or rocking grates, with no fire-brick arch.

(*b*) Same as *a*, with steam jet under a small combustion space.

(*c*) Plain or rocking grates, with a fire-brick arch, large combustion space, and provision for admitting air over the fire either at the front or at the bridge wall.

(*d*) Plain or rocking grates, with large or small combustion chamber and with or without fire-brick arch, equipped with steam jets and air-admission dampers which close automatically after each firing.

(*e*) Combinations of any two or more of the above.

(*f*) Down-draft furnaces, consisting of two grates, the upper one of water tubes to prevent its destruction by the heat, and the lower one like the common hand-fired grate. The fire is built on the upper grate, and coal is fed or shoveled on top of the fire. The furnace is so arranged that the gases and flame pass down through the upper grate and over the lower one, on which a fire of coke, supplied from the upper grate is maintained.

II. Those to which coal is fed continuously by an automatic device:

(*g*) Powdered-coal devices, in which particles of coal are thrown or blown into the furnace and burned before reaching the bottom of the combustion chamber, which must be of fire brick.

(*h*) Sprinkling stokers.—Devices for automatically feeding and distributing small sizes of coal as evenly as possible over the entire grate surface. Automatic shaking grates are usually installed with this apparatus.

(*i*) Coking stokers:

1. Overfeed stokers, in which the coal is fed continuously and coked under a fire-brick arch. Special provisions are made to admit air to mix with the volatile gases. These may be further subdivided into front-feed and side-feed stokers.
2. Traveling chain-grate stokers, in which the coal is fed at the front under a fire-brick arch and the entire surface of the gate moves toward the bridge wall at a rate which allows all the coal to be consumed.
3. Underfeed stokers, in which the coal is automatically fed at frequent intervals beneath the bed of hot fuel, air is forced through the burning coal by means of a fan, and as the volatile gases are given off from the fresh coal they mix with the air and pass up through the fire. Under favorable conditions combustion is completed within a short distance from the surface of the fuel bed.

DIFFICULTY IN SECURING PERFECT COMBUSTION.

With so great a variety of furnaces to choose from it seems at first thought that there should be no difficulty in abating smoke. It is, however, difficult to construct a furnace that will be smokeless under any and all conditions of operation. Some furnaces now in operation are practically so, conforming to every requirement outlined for smokeless combustion, but there is no type of grate or stoker on the market to-day which does not give off offensive black smoke in some of the plants in which it is installed. This may or may not be due to faults in the furnace. It may be due to lack of combustion space or to improper handling.

The efficiency of the furnace and the degree of success attained by any equipment in the prevention of smoke depend on the following factors: Skill of the fireman, proper design of the furnace and boiler setting, character of the coal, capacity of the boilers and furnaces, and load carried.

The skill of the fireman is the most important element in connection with the ordinary equipment. As a matter of fact, the personal element is the greatest hindrance to progress in the abatement of smoke. Both the owner and the fireman must be interested to obtain the best results. Intelligent supervision in the boiler room to secure proper air admission and care in firing will result in the saving of the losses due to smoke or unconsumed gases and to heating an excessive amount of air. At many plants such supervision has reduced the coal bills by 5 to 20 per cent, depending on the coal and the methods formerly in use.

It is a generally conceded fact that intelligent men trained in boiler-room practice could save 10 per cent of the fuel used in 50 per cent of the plants of the United States, and that in another 25 per cent of the plants such men could save 5 per cent of the fuel. It is the practice of nearly all large power plants to employ a boiler-room expert, and many of them have chemists who make frequent tests and investigations to determine the conditions favorable to the best economy. The saving of only a small percentage of the coal consumed will make a handsome return for the cost of the experimental work. There are now in a few of our larger cities competent engineers who are making a specialty of supervising boiler plants for a number of firms.

A few examples of carelessness and indifference on the part of firemen will in a measure explain why many persons are skeptical regarding the value of mechanical stokers and other smoke-preventing devices.

At a plant which had a smoke-preventing device, but which was smoking, the fireman said a connecting chain had been broken for several days and he "didn't have time to bother with it." It would not have required more than ten minutes to join the two ends with wire for a temporary repair. In another plant the fireman said: "The thing takes too much steam, and I shut it off." Many other cases of willful neglect have been observed.

Very few firemen can be induced to fire regularly and frequently, because it is easier to put in enough coal to last twenty or thirty minutes at one time and have little or nothing to do in the interval between firings. In one instance the engineer took occasion to measure the draft between the grates before and after firing on a down-draft furnace which had a good draft. The draft before firing was 0.35 inch of water, but after the fireman had thrown on 63 shovelfuls of coal the flow of air was so seriously retarded that the draft increased to 0.62 inch. Great volumes of smoke were given off, indicating this lack of air.

Professor Benjamin, in his paper on smoke and its abatement (see p. 23), speaking of steam and air jets, expressed himself as follows:

"It is a very effective method of smoke prevention, and is used very largely in Cleveland. I have not given it very much weight in my paper, because it depends so much upon the individuality of the engineer and fireman. I have found that men who use that means had to be watched so continually and reprimanded so much that I got out of patience with that sort of prevention."

Difficulties are also encountered with stokers. One of the greatest troubles is the tendency of the fireman to poke the fires unnecessarily instead of using or adjusting the attachments provided for feeding and handling the coal. In many plants where it is possible they will shovel green coal into the stokers, instead of feeding it through the hopper, and then take a bar and stir up the fresh coal with the coke and ashes, causing smoke and wasting the coal.

It is not an uncommon experience that on inspection the boiler tubes are found to be covered with scale on one side and soot on the other. One plant with nearly 4,000 horsepower had soot hanging from the surfaces of the tubes, and on inquiry it developed that these tubes had not been cleaned for a period of four months, no cleaning having been done since the new master mechanic had taken charge.

The following quotation is from the Manchester report, already cited (see p. 24):

Negligent management of the self-acting damper is responsible for much of the smoke from hand firing. * * * No doubt its use obviates to some extent the necessity for constant attention, but in many cases it has been disconnected after attention has been drawn to the smoke.

The foregoing examples emphasize the facts that the management of the boiler room is a problem for properly trained men and that as the coal burned is a considerable item of expense, averaging about 50 per cent of the cost of producing power, there is more opportunity to save in the boiler room than in the engine room with any given equipment. The average boiler room is a hot, dirty, and otherwise unattractive place. For these reasons but little attention has been paid to it by superintendents and operating engineers in moderate-sized plants. The boiler rooms are managed for the most part by men hired not so much for what they know as for their ability to do hard work, and they get comparatively small wages. There are, however, some mechanical appliances, such as the chain grate, which leave but little to the skill of the fireman. (See "Suppression of industrial smoke," by A. Bement, cited in bibliography, p. 23.)

Many furnaces may be classed as smokeless when attended by careful men, but unsatisfactory when fired by ordinary firemen. In some power plants it is difficult for even a trained man to secure reasonable economy and prevent smoke. This may be due to the fact that the plant is poorly designed. It does not follow that a plant having a high chimney will have a sufficient draft. The chim-

ney may be too small, or there may be many elbows in the flues leading from the boiler to the stack, or there may be serious leakage of air through holes in the flue, boiler setting, and breeching. A poor draft is responsible for a great deal of trouble in the boiler room. Difficulty in burning coal in some one furnace in a plant has been reported where investigation showed that the damper had turned on its shaft and instead of being open, as the fireman supposed, was nearly closed. Such difficulties can be avoided only by systematic supervision.

In many plants the grate surface is not properly proportioned to the load carried. This can be remedied in hand-fired furnaces, but not without considerable expense in stoker plants. Some plants maintain fires under too many boilers for good economy; on the other hand, there are probably more in which the furnaces are overloaded.

The hand-firing of plain furnaces violates all the principles laid down for securing good combustion. The coal is usually supplied in large quantities at long intervals, and the result is that at the times of firing the temperature of the furnace is lowered, the resistance to the flow of air through the fuel bed is increased, and consequently great quantities of combustible gas are generated which can not be burned for lack of air and the necessary amount of heat.

Hand-fired furnaces with steam and air jets may save enough by better combustion to make up for the cost of the steam used in the jets. They are looked upon as makeshifts by experienced smoke inspectors and others competent to judge of them.

Hand-fired furnaces with ample combustion chambers and adjustable openings for air admission are suitable for some kinds of coal, if tended by experienced and careful firemen.

Down-draft furnaces have shown decided economy in many plants and have been fairly successful in the prevention of smoke. The principle is a good one, but few installations of these furnaces are properly fired. Whether they can be run smokelessly depends on the required capacity, the kind and size of coal, and the attention.

Mechanical apparatus for burning powdered coal in boiler furnaces has been tried in many plants and with but few exceptions has been found unsatisfactory on account of the cost and difficulty of maintaining the furnace. It has, however, proved a decided success in firing cement kilns.

Sprinkling stokers have as yet made little headway in this country. Records given in the Manchester (England) smoke-prevention report show that these stokers are not as successful in preventing smoke as those of the coking type.

Furnaces with mechanical stokers of the overfeed types, including chain grates, which feed the coal gradually and coke it under a fire-brick arch, are used more widely than any others except the plain

hand-fired furnaces. When these stokers are properly installed in connection with ample combustion chambers, and carefully operated, they give good results and prevent smoke. Many of these furnaces are not properly installed and a still greater number are badly operated. The inclined-grate stokers will burn either high-volatile coals or coals high in fixed carbon. The chain-grate stokers are successful in burning high-volatile coals such as are found in Indiana and Illinois. They require less attention from the fireman than other types of stokers, and they can be operated smokelessly when properly installed. This stoker has not been adapted to burning low-volatile coals such as are largely used in the East.

Underfeed stokers that automatically feed the coal are usually successful with either high or low volatile fuels when properly installed and operated at a reasonable rate of combustion.

Many furnaces are burning coal unsuited to them, and under the load conditions it is impossible to prevent smoke. A change to another kind, or in some cases to another size of the same kind of coal, would prove satisfactory.

INDIRECT METHODS OF SMOKE ABATEMENT.

There is at present a general tendency to centralize power, heating, and gas plants. In the heating of buildings it is customary under existing conditions to generate steam in the building. Where this is done, it is in general considered more economical to install engines for generating current for light and power also. However, many buildings furnish their own heat, but purchase current. Large power or light plants can now be located at any convenient place, say at the coal mines, because of the ease and economy with which electric current can be transmitted; but heating plants, whether for residence or for business districts, must be within a comparatively short distance from the section to be heated on account of the cost of installation and the losses from radiation. There are now more than 150 central heating plants in the United States, furnishing steam or hot water to residences or business buildings or to both. The greater number of these plants are located in the coal-producing States. Some of them have been built especially for the purpose of heating; others are additions to electric-lighting or industrial plants and utilize the exhaust steam from the engines. These central plants can be operated without smoke under favorable conditions, and they relieve the smoke situation in a measure. The plan of purchasing both heat and light, not only for residences, but also for business houses, is popular because it relieves the consumer of the details of operating a plant, does away with the dust of coal and ashes, and makes available for storage purposes space which would otherwise be occupied by the plant.

It has been suggested that in certain types of furnaces in which perfect combustion can not be maintained, the resulting smoke may be washed from the chimney gases in the same way as dust and soot are now removed from the air that is used in ventilating large office buildings, schoolhouses, and hospitals.

The increasing use of storage batteries by street railways and other interests has aided in the prevention of smoke. These batteries furnish the extra power needed when traffic is heavy during rush hours on the street railways and make unnecessary any sudden heavy demands on the power plants. The load on the engines being more nearly uniform, there is less change in the rate of combustion in the furnaces and less smoke, for change of load and crowding of boilers constitute a most prolific source of smoke.

SUMMARY.

The increasing use of gas and coke for domestic, manufacturing, and power purposes and the centralization of power and heating plants tend to relieve cities of a large percentage of the smoke now given off by small and inefficient heating and power plants. Notwithstanding the fact that other ways of utilizing coal are growing in favor, it will evidently be necessary to burn coal in small boiler plants for some time to come. These coal-burning plants will continue to keep the problem of smoke abatement before the residents of large cities.

It is recommended that in order to improve the conditions in any city a record of all equipment and furnaces in the power plants be made, and that improvements, methods of operation, and the kinds of coal used be made a special study. It is only by such systematic methods that the local problem can be solved, as conditions in any one city are generally different from those in others, depending on the amount and kind of manufacturing and the character of the coal available.

The personal element is the most difficult obstacle to overcome in the fight against smoke. Study of the requirements and a desire to obtain good results on the part of the firemen will do more to clear the air in cities than any other one influence.

Being principally the result of an imperfect air supply, smoke can be prevented by providing for sufficient air and for its mixture with the gases in the furnace.

Well-designed furnaces may smoke to a greater or less degree, depending on the methods of the firemen, the kind or size of the coal, and the rate at which the coal is burned. They may be expected to give smokeless combustion when burning a suitable coal, except under the following unfavorable operating conditions:

1. When fires are built. The furnace not being heated to the required temperature, the gases cool below their ignition point and escape unburned.

2. When so much coal is burned on the grate that it is impossible to supply sufficient air without frequent poking. This condition usually results in so large a volume of gas from the coal that it can not be properly mixed with air and burned in the combustion chamber. On reaching the boiler surfaces it is cooled, combustion is arrested, and soot and smoke result.

3. When the rate of combustion is suddenly increased, as when more coal is added, and fires are poked to get up pressure in short time.

4. When the fires are checked by closing doors or dampers, thus cutting off the air supply. Banked fires are difficult to maintain and start up without smoke. Automatic dampers are frequently the cause of smoke when not properly adjusted or designed.

There is need of further study of coals, furnaces, and combustion, but enough is now known to enable an engineer to design and operate a steam plant without objectionable smoke.

BIBLIOGRAPHY.

SURVEY PUBLICATIONS ON COAL.

The following reports (except Bulletin No. 261) can be obtained by application to the Director of the United States Geological Survey, Washington, D. C.:

BULLETIN No. 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. Can be obtained by sending 10 cents in cash to the Superintendent of Documents, Washington, D. C.

PROFESSIONAL PAPER No. 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts, 1492 pp., 13 pls.

BULLETIN No. 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905. J. A. Holmes, in charge. 1906. 240 pp.

BULLETIN No. 323. Experimental work conducted in the chemical laboratory of the fuel-testing plant, St. Louis, January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

BULLETIN No. 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp.

BOOKS ON COMBUSTION AND SMOKE PREVENTION.

BARR, WILLIAM M. Combustion of coal and the prevention of smoke. Norman W. Henley Publishing Company, New York.

BOOTH, WILLIAM H., and KERSHAW, JOHN B. C. Smoke prevention and fuel economy. Norman W. Henley Publishing Company, New York, 1905.

HAYS, JOSEPH WELLER. Combustion and smokeless furnaces. Hill Publishing Company, New York, 1906. 104 pp., illustrated.

KENT, WILLIAM. Steam boiler economy: A treatise on the theory and practice of fuel economy in the operation of steam boilers. "Coal can be burned without smoke provided (1) the gases are distilled from the coal slowly; (2) that the gases when distilled are brought into intimate contact with very hot air; (3) that they are burned in a hot fire-brick chamber; (4) that while burning they are not allowed to come in contact with comparatively cool surfaces, such as the shell or tubes of a steam boiler. This means that the gases shall have sufficient space and time in which to burn before they are allowed to come in contact with the boiler surfaces."

PEABODY, C. H., and MILLER, E. F. Steam boilers: A treatise on boilers and furnaces. Chapter on combustion.

POPPLEWELL, WILLIAM CHARLES. The prevention of smoke combined with the economical combustion of fuel. Scott Greenwood & Co., London, 1901.

NICHOLSON, WILLIAM. Smoke abatement: A manual for the use of manufacturers, inspectors, medical officers of health, engineers, and others. C. Griffin & Co. (Limited), London, 1905. 59 illustrations.

WILLIAMS, CHARLES WYE. Combustion of coal and the prevention of smoke, chemically and practically considered. London and Liverpool, 1841; new ed., London, 1854.

PROCEEDINGS OF ENGINEERING SOCIETIES.

BEMENT, A. Suppression of industrial smoke, with particular reference to steam boilers. A paper presented before the Western Society of Engineers, October 17, 1906. 60 pp., 26 illustrations. With discussions by W. L. Abbott, Chicago Edison Company; R. H. Kuss, assistant smoke inspector, Chicago; Frank Elliott, chief engineer Northwestern Elevated Railroad, Chicago; W. L. Goddard, International Harvester Company; A. J. Saxe, supervising engineer, Chicago; Carl Scholz, president Coal Valley Mining Company; H. Kreisinger, fuel-testing plant, United States Geological Survey; E. H. Taylor, Fuel Engineering Company, Chicago; John C. Schubert, smoke inspector, Chicago. Communicated by letter: Prof. William Kent, Syracuse, N. Y.; F. S. Peabody, Peabody Coal Company; E. B. Powell, New York Edison Company; J. W. Green, Cedar Rapids, Iowa; H. W. Woodward, assistant smoke inspector, Cleveland, Ohio; H. E. Horton, Chicago; R. S. Moss; Philip McCarty, smoke inspector, Denver; Clinton Rogers, Rochester, N. Y.

BENJAMIN, CHARLES H. Smoke and its abatement. Trans. Am. Soc. Mech. Eng., vol. 26, New York, 1905, p. 713. Discusses, in a general way, the methods employed for preventing smoke in stationary plants and on locomotives.

HARTMAN, JOHN M. Notes on burning bituminous coal. Proc. Eng. Club, Philadelphia, April, 1904.

MABERY, C. F., and BENJAMIN, CHARLES H. Economy in combustion and smoke prevention. Jour. Assoc. Eng. Socs., May, 1896. Doctor Mabery discusses the chemical aspect of the combustion of coal; Professor Benjamin discusses smoke prevention from the mechanical standpoint. Good smoke-preventing device should have variable feed, variable spacing of grate bars, grate bars of the automatic shaking type, some form of air control, sufficient grate area, easy accessibility for cleaning, good firing.

ROWAN, F. J. The smoke problem. Trans. Inst. Eng. and Shipb. Scotland, October, 1904. Discusses the production of smoke; the estimation of smoke; the prevention of smoke; some considerations affecting municipal control.

SHAW, W. N. The treatment of smoke. Jour. San. Inst., October, 1902. Discusses the removal of smoke as a parallel to the removal of sewage.

FRANKLIN INSTITUTE. The smoke nuisance and its regulation, with special reference to the condition prevailing in Philadelphia. Jour. Franklin Inst., June, 1897. Discussion showing that smoke prevention is possible. R. H. Thurston says preventives are legislation, skilful operation of furnaces, and special construction of furnaces. "I am inclined to expect highest efficiency, ultimately, through the use of the mechanical stoker."

PUBLICATIONS BY STATES, CITIES, AND CITIZENS' COMMITTEES.

BRECKENRIDGE, L. P. The prevention of smoke. Engineering Experiment Station, Urbana, Ill.

BUFFALO. The abatement of the smoke nuisance. Committee of manufacturers of the chamber of commerce. Contents: To whom smoke prevention is beneficial; the present and the proposed ordinance; ordinances of the cities of New York, Pittsburg, Cleveland, Detroit, Syracuse, Rochester, Minneapolis, Cincinnati, and Indianapolis.

CLEVELAND. Report of the municipal committee on the smoke nuisance, March, 1907. Contents: Effect of coal smoke; attempt to enforce ordinance of 1882; discussion of question "Is there a mechanical device which will prevent the emission of smoke?" legal basis requiring its installation; responsibility of the owner; review of the present ordinance of the city; recommendations.

——— Smoke prevention and economy. Department of smoke abatement, February, 1905. Contents: Determining factors of smoke abatement; description of smoke-prevention devices; smoke prevention and fuel economy synonymous; answers to query "Can smoke be prevented?" from tests and letters.

MANCHESTER (England). Report of committee for testing smoke-preventing appliances, 1895. Contents: Origin of the movement; scope of the work; details regarding tests; deductions from smoke observations; tables of results of tests. 42 pp., 3 illustrations, and 10 important tables.

MILWAUKEE. Second annual report of Charles Poethke, smoke inspector, 1905. Contents: Smoke-preventing devices installed; an indication of fuel economy; cooperation of manufacturers; gratifying results; imperfections of ordinance.

ST. LOUIS. Report of the smoke abatement department, C. H. Jones, chief inspector, October, 1906. Contents: Smoke-consuming devices (classified) in use; difficulties of the department; effect of insufficient boiler capacity.

——— The smoke nuisance. Report of the smoke-abatement committee of the civic league, November, 1907. Contents: Injurious effects of smoke; damage to plant life; smoke and fuel economy; does smoke come from East St. Louis? the problem of the committee; the first ordinances invalid; the present ordinance valid; kinds of fuel used in St. Louis; principles of proper combustion; smoke devices in use; prolific causes of smoke; comparison of devices in use; smoking locomotives the most reckless offenders; brick kilns as smoke makers; does enforcement of ordinance mean persecution; three important factors for the solution of the smoke problem; *draft* of the new ordinance.

SYRACUSE. Report upon smoke abatement. Chamber of commerce committee, 1907. Contents: Damage done by smoke; results in other cities; principle of combustion; causes of smoke; devices for preventing smoke; railroad smoke; economic results from smoke abatement; conclusions.

PAPERS IN TECHNICAL JOURNALS.

BEILBY, GEORGE THOMAS. Smoke abatement. Engineering, June 26, 1903. Advocates the substitution of gas fuel for coal.

BENJAMIN, CHARLES H. Smoke and its abatement in large cities. Tech. Quart., September, 1902.

——— The prevention of smoke from bituminous coal. Engineer (U. S.), April 1, 1903.

BOOTH, W. H. Smoke prevention. Am. Machinist, September 29, 1898. Discusses principles of combustion and the requirement of a furnace so that it may not produce smoke.

——— Smoky furnaces and how to avoid them. Elect. Review, London, 1st part, July 26, 1901.

——— The smokeless combustion of bituminous fuels. Elect. Review, London, September 26, 1902. Discusses principles of combustion.

BRECKENRIDGE, L. P. Burning Illinois coal without smoke. Eng. News, June 11, 1903. The essential features of a smokeless plant are sufficient boiler capacity, a good draft, uniform size of coal, some good type of automatic stoker, intelligent direction in the boiler room.

CARY, ALBERT A. The suppression of smoke in steam plants using bituminous coal. Iron Age, October 2, 1902. "The whole secret of burning coal smokelessly is to obtain complete combustion in the furnace or combustion chambers before any appreciable amount of the combustible gases meet the chilling water surfaces of the boiler. No one furnace setting can be built to burn all kinds of fuel with equal efficiency."

——— The prevention of smoke. Eng. Record, vol. 53, April 21, 1906, pp. 514–516. Condensed from an address before the New York section of the Society of Chemical Industry. Smoke prevention depends on intelligence in the boiler room, proper design of the grate to burn the particular kind of coal used to the best advantage, proper design of the furnace and combustion chamber.

DONKIN, BRYAN. On smoke and its diminution. Engineer, London, May 26, 1899. Discusses methods in use for diminishing smoke.

HEMPEL, W. On smokeless combustion and boiler firing. Abstract from "Stahl und Eisen." Colliery Guardian, July 24, 1896. Discusses influence of temperature and pressure on gaseous products of combustion.

KERSHAW, JOHN B. C. Industrial smoke and its prevention. Cassier's Magazine, vol. 29, December, 1905, pp. 109–114. Reviews a number of earlier works on smoke abatement and concludes that the method of preventing smoke is good stoking and scientific control.

——— Smoke abatement: A report on the London smoke-abatement conference, December 13–15, 1905. Cassier's Mag., vol. 29, February, 1906, pp. 335–341.

KING, R. P. The abatement of the smoke nuisance. Municipal Engineering, vol. 29, November, 1905, pp. 366–369. Gives municipal aspect of the smoke problem. "Of the successful devices there are four classes—steam jets, furnaces, mechanical stokers, smokeless coal."

LONDON. Conference on smoke abatement; abstract of proceedings. Engineer, London, November–December, 1905.

MAYNER, WILLIAM. Smokeless combustion and economy of fuel. Sci. Am. Suppl., vol. 60, August 26, 1905, pp. 24788-24789. Discusses the waste obtained by burning coal in ordinary furnace. Describes the furnace invented by Charles Wegener, of Charlottenburg.

PARKER, T. T. Smoke abolition. Am. Machinist, October 16, 1902. Two ways of changing horizontal tubular boilers so that they may be made smokeless.

POPPLEWELL, W. C. The smoke problem and its possibilities. Feilden's Mag., December, 1902. Article describes several different stokers.

RAWORTH, JOHN S. The prevention of smoke. Electrician, London, September 26, 1902. Describes test made with Wilson smokeless process by Electric Traction Company at Kidderminster.

SIMMERBACH, O. The suppression of smoke by the use of coke. (From Zeitschrift der Dampfkessel-Ueberwachungs-Vereine.) Progressive Age, February 15, 1897. Discusses the advantages presented by coke for use under boilers as compared with coal.

WILKINSON, THOMAS L. The smoke problem of Denver. Min. Reporter, December 10, 1903. Discusses the general principles of combustion and several devices for smoke prevention.

WRIGHT, J. The possibilities of electrical smoke deposition. Elect. Review, London, November 23, 1900. Discusses the possibilities of electrical smoke deposition, cites several laboratory experiments to show that it is possible, and suggests a plan by which it might be attempted in practice.

An improvement in smoke-consuming furnaces. Sci. Am., March 31, 1900. Describes a smoke-preventing attachment for hand-fired furnaces.

Apparatus for consuming smoke. Sci. Am. Suppl., February 25, 1899. Brief review of the report of the commission appointed in Paris for testing smoke-consuming apparatus.

Smoke. Progressive Age, September 15, 1898. Editorial, discussing the probability of avoiding the smoke nuisance by substituting gas for coal.

Smoke abatement. Engineering, August 7, 1896. Editorial review of smoke problem, particularly of the report of the "committee for testing smoke-preventing appliances."

Smoke prevention and smokeless furnaces. Eng. News, January 2, 1896. Discusses briefly conditions of combustion, waste due to smoke, and hygienic questions.

The smoke nuisance. Builder, August 12, 1899. General discussion of the smoke nuisance with particular reference to the waste caused by smoke from domestic fires and the damage done to property, etc., by smoke.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 334.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at practically cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Foresty; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports; Q, Fuels; R, Structural materials. This paper is the eighth in Series Q, the complete list of which follows (PP=Professional Paper; B=Bulletin):

SERIES Q, FUELS.

B 261. Preliminary report of the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp.

PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. 3 parts. 1,492 pp., 13 pls.

B 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp.

B 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

B 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., in 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp.

B 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to July 1, 1907, Joseph A. Holmes in charge. 1908. —— pp.

B 333. Coal-mine accidents: their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling, with an introduction by J. A. Holmes. 1907. 21 pp.

B 334. The burning of coal without smoke in boiler plants, a preliminary report, by D. T. Randall. 1908. 26 pp.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

JANUARY, 1908.

O

Bulletin No. 335

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGY AND MINERAL RESOURCES

OF THE

CONTROLLER BAY REGION, ALASKA

BY

G. C. MARTIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

CONTENTS.

	Page.
Preface, by Alfred H. Brooks	7
Introduction	9
Location	9
History of investigations	9
Early explorations and surveys	9
Geologic and topographic surveys	10
Acknowledgments	13
Commercial developments	14
General character of the country	15
Topography	15
Glaciers	16
Streams	16
Climate	17
Vegetation	19
Settlements	20
Transportation	20
Existing facilities	20
Railway routes	21
Harbors	22
Routes	23
Geology	24
General features	24
Neighboring provinces	25
Description of the rocks	26
Pre-Tertiary	26
Tertiary	27
Katalla formation	27
Description	27
Fossils	28
Stillwater formation	30
Description	30
Fossils	31
Kushtaka formation	31
Description	31
Fossils	34
Tokun formation	35
Description	35
Fossils	36
Undifferentiated	36
Age and correlation	37
Igneous rocks	41
Structure	42

Geology—Continued. Page.
Description of the rocks—Continued.
Quaternary 46
Marine silt and clay 46
Glaciers 46
Bering glacier 46
Description 46
Moraine 47
Marginal lakes 47
Martin River glacier 48
Description 48
Moraine 49
Marginal lakes 49
Minor glaciers 49
Glacial deposits 50
Moraine 50
Lake deposits 52
Stream and beach deposits 52
Description of land forms 53
Adjacent regions 53
Shore line 54
Drainage 55
Rivers 55
Lakes 56
Relief 57
Distribution of the hills 57
Accordance of elevations 57
Crest lines 57
Terraces and benches 59
Significance of crest and bench levels 60
Valleys 60
Historical geology 61
Mineral resources 65
Coal 65
Areal extent 65
Stratigraphic position 66
Description of the coal beds 66
Character of the coal 81
Physical properties 81
Combustion 82
Coking tests 82
Chemical and calorimetric properties 83
Analyses and calorimeter tests 83
Methods of sampling 83
Methods of analysis 83
Analyses 83
Classification of the coal 88
Schemes of classification 88
Variation in character 90
Comparison with other coal 92
Prospective mining conditions 92
Position of the coal 92
Attitude of the coal 93
Persistence of the coal 93

Mineral resources—Continued. Page.
Coal—Continued.
Prospective mining conditions—Continued.
Physical condition of the coal 94
Presence of water and gas 94
Shipment 94
Markets 95
Consumption of fuel in Alaska 95
Amount and sources 95
Disposal 96
Prospective increase in use of coal 97
Competition with petroleum 98
Use of petroleum in Alaska 98
Effect of California petroleum on Pacific coast coal trade 98
Capability of coal to compete with petroleum 101
Relative adaptability 101
Relative efficiency 101
Relative prices 104
Available supply 105
Competition with other coal 106
Alaska coal 106
Distribution and area 106
Pacific coast region 107
Interior region 108
Bering Sea and Arctic slope 108
Developments and production 108
Character of Alaska coal 109
Imported coal 110
Petroleum 112
Introduction 112
Location of the oil field 112
Geologic conditions in the oil belt 112
Developments 113
Occurrence of petroleum 113
Seepages 113
Geographic distribution 113
Relations to kinds of rock 114
Relation to structure 114
Description 116
Wells 119
Character of the petroleum 121
Principles governing the occurrence of petroleum 124
Exploitation 126
Locating pools 126
Difficulties of drilling 127
Crooked holes 127
Caving 127
Water 127
Remoteness from supplies 128
Inexperience with local conditions 128
Cost of labor and transportation 128
Shipment and markets 128
Conclusions 129
Bibliography 130
Index XXV

ILLUSTRATIONS.

		Page.
PLATE I.	Topographic map of Pacific coast from Yakutat Bay to Prince William Sound	10
II.	Topographic map of Controller Bay region	Pocket.
III.	Sketch map of Controller Bay region, showing position of triangulation stations	12
IV.	*A*, Chugach Mountains and Martin River Glacier from Monument Mountain; *B*, Volcanic plug at the south end of Kayak Island	16
V.	Geologic map and sections of the Controller Bay region	Pocket.
VI.	*A*, First Berg Lake with Bering Glacier in the background, looking south; *B*, Bering Glacier, showing ice cliffs on edge of Bering River	46
VII.	*A*, Lower end of Bering River canyon; *B*, Headwaters of Bering River at the upper end of the canyon at the south end of Carbon Mountain	54
VIII.	Map of Bering River coal field, showing coal areas, location of coal sections, and localities from which samples were taken	Pocket.
IX.	*A*, Valley of Sheep Creek, showing coal outcrops on the mountain face; *B*, Natural coke and diabase sills at the south end of Carbon Mountain	92
X.	Map of Alaska showing distribution of coal	106
FIG. 1.	Sketch of structure on a creek in the northeast part of the Bering River coal field	42
2.	Map of Controller Bay oil field, showing location of oil wells and seepages	113

PREFACE.

By Alfred H. Brooks.

This volume presents the results, both geologic and topographic, of the first detailed survey made of any of the Alaska coal fields. Most of the other important coal fields have been covered by surveys of a reconnaissance character (see p. 130, this report), and it is purposed to carry detailed surveys over them as fast as they are likely to be rendered accessible by transportation facilities, provided the means permit.

It is an established policy in the investigation of the mineral resources of Alaska to precede detailed work by that of a reconnaissance character. This makes it possible to determine not only the areas of probably greatest commercial importance, which should be surveyed in detail, but also to obtain an insight into the larger geologic problems and thus pave the way for the more detailed investigations. The following report is the result of such a policy, a general investigation of the fuel resources and of the geologic problems connected therewith of the Pacific coastal belt of Alaska,[a] made in 1903–4, having indicated the Controller Bay region as the part of this province which gave promise of being of greatest immediate commercial importance.

It is considered desirable that areas selected for survey, especially those for mapping in detail, should be of quadrilateral outline and bounded by parallels of latitude and meridians of longitude. Unfortunately the means at hand are not always sufficient to cover such quadrangles, and the work is perforce confined to the parts that are of greatest commercial importance. Such is the case in the accompanying map (Pl. II, pocket) of the Controller Bay region.

The maps and text of this volume present many details of the geology. If, as is often the case, a tentative rather than a final conclusion is presented, it should be regarded as being due both to the lack of comprehensive knowledge of the whole Alaska-Pacific coast

[a] Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905. Moffit, F. H., and Stone, R. W., Mineral resources of Kenai Peninsula, Alaska: Bull. U. S. Geol. Survey No. 277, 1906.

province and to the lack of bed-rock exposures, which is so characteristic of much of the region, rather than to a lack of refinement in field methods. The succession of Tertiary rocks in the northwestern Pacific-coast province of America is but very imperfectly known, and the included floras and faunas have been but little studied. Mr. Martin had, therefore, very little except the position of the beds to aid him in his interpretation of structure, which is very intricate. Though the stratigraphic sequence, as here presented, leaves much to be desired, yet it is undoubtedly the best that can be done until the Tertiary rocks are studied in adjacent provinces.

Though the region lies near the coast yet it is by no means easy of access. The heavy timber and swamps of the lowlands, the fewness of roads and trails, and the excessive rainfall made the work exceedingly arduous. In view of these facts, Mr. Martin and his assistants deserve great credit for the results obtained.

GEOLOGY AND MINERAL RESOURCES OF THE CONTROLLER BAY REGION, ALASKA.

By G. C. Martin.

INTRODUCTION.

LOCATION.

Controller Bay is a shallow indentation in the Pacific coast of Alaska, sheltered chiefly by Kayak and Wingham islands. It lies in latitude 60° north, longitude 144° west, being about 1,250 miles northwest of Seattle, 400 miles northwest of Sitka, and 15 miles east of the mouth of Copper River (Pl. I). The region here to be described includes the shores of Controller Bay, the islands in and around it, and an area extending for about 25 miles inland, including the entire drainage basins of Bering River and of the other streams emptying into Controller Bay, and parts of the headwater areas of the neighboring streams. This region, which extends for maximum distances of 37 miles from north to south and 28 miles from east to west, covers a total land area of about 430 square miles. It is an isolated region of lowlands and hills of moderate altitude, hemmed in between the Chugach Mountains and the sea on the north and south and between Bering Glacier and the Copper Delta on the east and west.

HISTORY OF INVESTIGATIONS.

EARLY EXPLORATIONS AND SURVEYS.

When Bering led the first exploratory voyage across the North Pacific in 1741, Cape St. Elias was his first landfall and either Kayak or Wingham Island his first landing place. The first exploration of this province thus dates back to the beginning of Alaskan history. But this beginning, although of historical interest, was of little importance, for Bering merely sent boats ashore for water, and then went back across the Pacific without extending his explorations or even touching on the mainland.[a]

[a] Steller, Georg Wilhelm, Beschreibung der See-Reise von Kamschatka nach Amerika, Frankfurt, 1774.

The Russians probably made other visits to Controller Bay during the beginning of settlement and fur trade from 1762 to 1783, but if so they left no records which are accessible. Other explorers sent out by the Russians, French, and Spaniards sailed past this coast, but there is no record of their having landed here.

Vancouver and Puget, returning from Cook Inlet in 1794, entered Controller Bay, and the latter spent considerable time there while attempting to sail out through the channel between Kayak Island and Okalee Spit. Puget's account of this work and his descriptions of the regions [a] are especially complete.

Controller Bay and the coast eastward were visited in 1837 by Sir Edward Belcher, who wrote [b] some rather elaborate but nonscientific descriptions of Bering and Malaspina glaciers.

Lieut. H. W. Seton-Karr, after attempting to climb Mount St. Elias in 1886, cruised westward in a small boat, spent some time at a settlement on the north end of Kayak Island and near Katalla, and crossed the Copper Delta. He published a very complete narrative [c] of his journey, with general descriptions of the country and with sketches.

All the charts of Controller Bay and the neighboring coast published prior to 1903 were based on early surveys, probably by Tebenkof. The United States Coast and Geodetic Survey mapped the Copper Delta in 1898 and made detailed surveys of parts of the shore line and waters of Controller and Katalla bays in 1903, 1905, and 1906. The results of this work are embodied in chart No. 8513.

GEOLOGIC AND TOPOGRAPHIC SURVEYS.

The earliest authentic references to the geology and mineral resources of this region were by Oliphant,[d] Eldridge,[e] Spurr,[f] Kirsopp,[g] Stoess,[h] and others.[i]

The facts to be presented in this volume have been gathered chiefly during visits to the region made by the writer during each of the last

[a] Vancouver, Capt. George, Voyage of discovery to the North Pacific Ocean, etc., in the years 1790–1795, London, 1798, 3 v. (maps).

[b] Belcher, Capt. Sir Edward, Narrative of the voyage of H. M. S. Sulphur during the years 1836–1842, London, 1843.

[c] Seton-Karr, H. W., Shores and Alps of Alaska, London, 1887, pp. 138–168.

[d] Oliphant, F. H., Petroleum, in Mineral Resources U. S. for 1897; Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, p. 110.

[e] Eldridge, G. H., The coast from Lynn Canal to Prince William Sound: Maps and descriptions of routes of exploration in Alaska in 1898, a special publication of the U. S. Geol. Survey, 1899, pp. 103–104.

[f] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 263–264.

[g] Kirsopp, John, jr., The coal fields of Cook Inlet, Alaska, U. S. A., and the Pacific coast: Trans. Inst. Min. Eng. (England), vol. 21, 1901, pp. 556–559.

[h] Stoess, P. C., The Kayak coal and oil field of Alaska: Min. and Sci. Press, vol. 87, 1903, p. 65.

[i] See bibliography on p. 130.

The Russian
ing the beginn
but if so they
sent out by th
coast, but there
Vancouver a
Controller Bay
tempting to sa
Okalee Spit.
the regions[a] a
Controller B
Edward Belche
descriptions of
Lieut. H. W
Elias in 1886, c
a settlement on
crossed the Co
tive[c] of his jou
with sketches.
All the charts
lished prior to 1
kof. The Unite
per Delta in 189
and waters of C
The results of th

The earliest
sources of this
sopp,[g] Stoess,[h] a
The facts to b
during visits to t

[a] Vancouver, Capt.
years 1790–1795, Lo
[b] Belcher, Capt. Si
years 1836–1842, Lo
[c] Seton-Karr, H. W.,
[d] Oliphant, F. H., I
Rept. U. S. Geol. Surv
[e] Eldridge, G. H., T
scriptions of routes of
Geol. Survey, 1899, p
[f] Spurr, J. E., A rec
U. S. Geol. Survey, pt.
[g] Kirsopp, John, jr.,
coast: Trans. Inst. M
[h] Stoess, P. C., The
1903, p. 65.
[i] See bibliography o

four years. A four weeks' reconnaissance was made in the summer of 1903, the results of which were published both in abstract [a] and in detail.[b] In 1904 about ten days were spent in supplementary reconnaissance, the results of which were incorporated in the detailed report [b] on the preceding season's work and were also presented more fully [c] by themselves.

More detailed surveys and investigations were made during the field season of 1905, when a combined geologic and topographic party of ten to twelve men was at work in the region from May 21 to October 27. The objects were to prepare a detailed topographic map, to plat the geology upon this base map, and to make the other detailed studies of the geology and mineral resources on which this report is based.

The topographic mapping, which was carried over an area of about 430 square miles, included all of the area within which there are indications of petroleum, and all of those parts of the coal field within which there have been actual or attempted developments. The work of the topographers was much aided by the use of the primary triangulation made by the Coast Survey and by detailed topographic maps of the coal and oil lands of the Alaska Development Company and the Pacific Coal and Oil Company made by Mr. J. L. McPherson. These maps were thoroughly tested in the field by both the topographers and the geologists and were found to be of rare accuracy and excellence. Accordingly the areas covered by them were not resurveyed, and Mr. McPherson's maps were reduced to the scale of and incorporated in the topographic map here published. This map (Pl. II, pocket) was surveyed on the scale of 1:45000 and is here published on the scale of 1:62500, or about 1 mile to the inch, with a contour interval of 50 feet. Bad weather prevented the extension of primary triangulation into the northeastern part of the area. The control of this section was consequently based on secondary plane-table triangulation and is subject to more or less correction. It is hoped that the errors will not be appreciable.

The approximate positions of the Coast Survey triangulation stations are shown on Pl. III, and are also stated in the following table:

---

[a] Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382.

[b] The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, 64 pp.

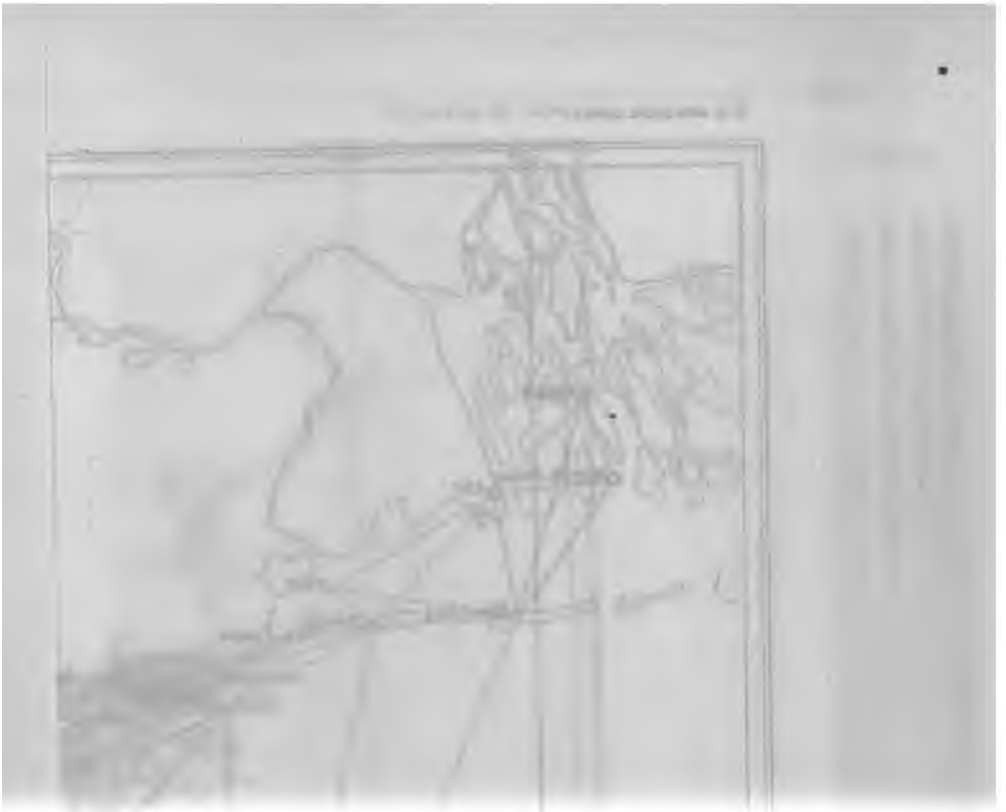
[c] Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139. Bering River coal field: Bull. U. S. Geol. Survey No. 259, 1905, pp. 140–150.

Latitude and longitude of Coast Survey triangulation stations.

Name of station.	Latitude.			Longitude.		
	°	′	″	°	′	″
Aid	60	17	56.390	144	56	13.535
Bald	60	21	33.511	145	02	43.403
Beach	60	10	37.890	144	28	31.280
Bert	59	59	58.428	144	12	02.568
Bit	60	09	26.360	144	25	16.853
Bum	60	10	40.147	144	28	37.502
Bunk	60	10	46.956	144	14	25.716
Bust	60	09	40.967	144	15	21.464
Calm	60	06	37.45	144	16	03.124
Cat	60	11	20.25	144	19	00.464
Cave	60	09	37.993	144	26	28.033
Chilcat	60	11	33.882	144	13	36.102
Cinch	60	08	44.345	144	21	54.708
Cut	60	00	23.074	144	13	51.720
Dune	60	12	22.550	144	40	50.626
East Base Controller Bay	60	01	40.487	144	11	42.532
Easy	60	08	52.866	144	23	07.608
End	60	11	35.404	144	31	01.397
Fall	60	04	46.166	144	22	09.977
Flat	60	14	23.135	144	44	48.838
Fox	60	09	48.358	144	36	29.732
Gable House	60	01	48.043	144	14	14.533
Grass	60	11	12.33	144	20	02.204
Green	60	02	28.554	144	23	21.701
Hey	60	10	00.653	144	22	28.436
Hump	60	13	02.513	144	46	39.901
Hunt	60	04	18.672	144	17	54.685
Isle	60	10	43.80	144	16	03.484
Jack	60	07	41.626	144	22	02.189
Last	60	10	58.981	144	33	17.610
Late	60	01	27.520	144	02	06.774
Lost	60	08	29.64	144	13	27.564
Marsh	60	11	05.99	144	17	06.604
Mid	60	11	07.248	144	29	48.081
North	60	07	32.62	144	20	14.624
North Base	60	18	31.349	145	05	10.598
Pen	59	59	08.63	144	22	39.164
Pinnacle Rock	59	47	25.018	144	36	36.745
Pyramid Peak	59	55	45.6	144	24	43.4
Rain	60	08	33.948	144	14	42.987
Red	59	59	55.824	144	22	34.089
Reef No. 1	60	13	10.599	144	57	45.140
Rise	60	04	00.952	144	21	03.974
Rock	60	00	28.07	144	13	41.15
Rush	60	05	17.244	144	20	03.101
Scraggy	60	10	35.330	144	33	46.962
Slope	59	59	23.033	144	17	42.692
Snag	60	11	05.03	144	20	48.264
Spit	59	59	17.045	144	19	47.045
Stump	60	10	46.955	144	36	06.068
Trap	59	57	38.422	144	22	08.110
Wade	60	06	12.277	144	20	03.958
West Base Controller Bay	60	01	44.389	144	14	53.313
Wing	60	02	59.539	144	23	33.608

About 45 miles of precise levels were run in the course of the detailed topographic work and 11 permanent bench marks were left. The line of levels extends from tide at Katalla to the mouth of Canyon Creek via Bering River, with branches up Shepherd Creek to Canoe Landing and up Stillwater Creek to Lake Kushtaka.

The following table gives the position and elevation of bench marks which were established by this precise leveling. All are marked by aluminum tablets set in rock, and the position is also indicated on the topographic map.



Bench marks in Controller Bay region.

Location.	Elevation stamped on tablet.	Adjusted elevation.[a]
	Feet.	*Feet.*
Katalla, 300 feet west of post-office; tablet set in top of large bowlder (5 by 10 by 10 feet)	10	10.095
Point Hey; tablet set in outcrop of sloping smooth sandstone	10	9.909
Mouth of Bering River; tablet set in base of cliff between waterfall and office of Pacific Coal and Oil Co	8	8.052
Bering River, west bank, 1 mile southeast of Bering Lake and ⅛ mile west of mouth of Gandil River; tablet set in sandstone	7	6.648
Shepherd Creek, west bank, near mouth; tablet set in sandstone 20 feet from water line, on low grassy swale between hills	6	6.067
Shepherd Creek, west side, on trail at base of steep hills; tablet set in sandstone outcrop 100 feet south of cabin at tunnel	47	47.049
Bering River, north bank, 4½ miles west of mouth of Stillwater Creek; tablet set in sandstone ledge at base of 20-foot cliff in first timbered hill above Bering Lake	21	21.094
Bering River at mouth of Stillwater Creek; tablet set in sandstone at base of 20-foot cliff, 50 feet south of gully on west side of creek	23	23.020
Stillwater Creek, 2¾ miles above its mouth; tablet set in sandstone on edge of trail ¾ mile above Cunningham's warehouse	49	49.160
Lake Kushtaka at outlet; tablet set in sandstone 20 feet from edge of water	85	84.728
Bering River, about 500 feet north of mouth of lower fork of Canyon Creek; tablet set in black sandstone on wooded point at west side of gravel flat, about 500 feet north of point where trail leaves Bering River	45	45.010

[a] The determination of mean tide at Katalla is based on observations extending for only twenty-four hours, and consequently is only approximate. The adjusted elevations of the bench marks as given in the table are regarded as correct within 0.1 foot with reference to the Katalla bench, but are subject to a probably greater correction on more accurate determination of mean tide.

Reconnaissance surveys were also made in 1905 to connect with the maps of the Copper River region. During the following season the reconnaissance topography was extended to the north and east. The data thus obtained were used in the preparation of Pl. I, in compiling which earlier maps by the Geological Survey in neighboring regions and by the coast and boundary surveys were also employed.

The geologic work of 1905 was carried over the same area as the topography, and a geologic map showing the distribution of the several formations was prepared (Pl. V, pocket). Numerous sections were measured and coal samples were collected at most of the more important openings. The results of this work have already been published in abstract,[a] but are given more completely on subsequent pages. Part of the season of 1906 was spent in completing the geologic work begun in the preceding year. The results of that year's work were also incorporated in an abstract report[b] which has already appeared.

ACKNOWLEDGMENTS.

The writer wishes to express his indebtedness and thanks to Mr. Alfred H. Brooks and Mr. W. W. Atwood, who were in consultation with him in the field; to his geologic assistants, A. G. Maddren, Lawrence Martin, Sidney Paige, R. W. Stone, and C. E. Weaver; and to

[a] Distribution and character of Bering River coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 65–77.

[b] Petroleum at Controller Bay, Alaska: Bull. U. S. Geol. Survey No. 314, 1907, pp. 89–103.

E. G. Hamilton and W. R. Hill, who made the topographic survey, and their assistants, F. E. Laube and W. J. McDonald.

Acknowledgments should also be made to the other members of his parties and to the many prospectors, operators, and engineers who by the aid and information they have given and the unfailing kindness they have shown have contributed much both to the value of the work and to the ease and pleasure of its accomplishment. The list of these men is too long to publish here, but the writer wishes to assure them that it is not too long for him to remember.

COMMERCIAL DEVELOPMENTS.

The first white men who settled in this region were traders who were attracted by the sea otters which the natives had for a long time been catching around the rocks off Kayak and Wingham islands. Trading posts were established during the Russian occupation, and soon after the transfer the Alaska Commercial Company is said to have had a station here. After the decline of the sea-otter industry attempts were made to establish salmon canneries, but they were not successful, although a cannery on Prince William Sound still finds it profitable to send steamers to Bering River for fish.

The existence of coal and petroleum was probably learned from the natives. However that may be, these materials began to attract attention in 1896 and soon brought in large numbers of prospectors. The first oil well was begun in 1901, and drilling has been in progress more or less actively ever since. (See p. 113.) A producing well was obtained in 1902 and an oil boom resulted. Companies were floated on cheap stock and promises, large areas of mud and ice were staked and sold, and drilling was begun wherever any kind of rig could be procured and landed. A large number of the oil companies never progressed beyond the sale of stock, and some possibly never intended to do so. Others began operations without obtaining competent advice and with no idea of the problems before them. A few started in a conservative, intelligent way to thoroughly test the field. None have thus far secured any return. It is now realized that oil drilling in a new field is uncertain, and at best requires time and money, and that Alaska oil fields are at a greater disadvantage than more accessible localities. It is still doubtful how and where producing wells are to be obtained and uncertain whether even successful wells will justify the present high cost of drilling and operating in this region.

The coal was discovered at about the same time as the petroleum. Probably all of the coal land within easy reach has now been located. The lands have been for the most part surveyed for patent application by deputy mineral surveyors. A large number (probably several hundred) of surface prospect openings have been made, and about 20 tunnels have been begun.

Complete title[a] has not, so far as is known to the writer (1907), been obtained by any of the locators, either here or elsewhere in Alaska.

The importance of transportation has been realized from the beginning of the development of the region. The building of trails and roads has gone on from year to year until foot travel is now easy. Railroad preliminaries have been in progress at intervals for several years, the following routes having been surveyed: From the east shore of Controller Bay to the valley of Shepherd Creek; from Point Hey to Shepherd Creek via Katalla Valley; from Whale Island, via Katalla Valley, to Lake Charlotte and thence to Copper River and into the interior; from Katalla Bay to Copper River and thence up Copper River; and from Canyon Creek to Controller Bay.

Construction of wharves and breakwaters at Katalla Bay and at Whale Island and of two railroads was begun in 1907.

GENERAL CHARACTER OF THE COUNTRY.

TOPOGRAPHY.

The Controller Bay region constitutes an area of lowlands and of hills of moderate height, lying between the Chugach Mountains and the sea on the north and south and between Bering Glacier and the Copper Delta on the east and west.

The Chugach Mountains are high and rugged (see Pl. IV, *A*), most of the prominent peaks having elevations of from 6,000 to 12,000 feet, and send out long spurs toward the southwest, which gradually decrease in height as they approach the sea. The hills and mountains of the northern and western parts of this region are such spurs. Most of the other hills stand as isolated peaks and ridges or as isolated groups, which are either surrounded by water, as the ridges on Kayak and Wingham islands, or by mud and gravel flats, as Mount Campbell, Nichawak Mountain, Gandil Mountain, and the group of hills south of Bering Lake. The elevation of the mountains within the area described in this report is in general less than 2,000 feet, and does not exceed 2,500 feet, except in the western and northern parts of the region, where numerous peaks rise to heights of from 2,500 to 4,150 feet. The highest of the summits are in the extreme northeastern part of the region, close to the Chugach Mountains. The hills are in general characterized by steep, canyon-gashed slopes below timber line, rounded peaks and flattish areas between timber line and an elevation of 1,800 to 2,000 feet, and sharp peaks and ridges above 2,000 feet.

[a] See Coal-land laws and regulations thereunder (a pamphlet issued by the General Land Office April 12, 1907), pp. 12–19.

GLACIERS.

Bering Glacier, which borders the region on the east, is a huge, even-surfaced, stagnant mass of glacial ice, which is fed by many valley glaciers coming from the high mountains north of it. It is a piedmont glacier of the same general character and of about the same size as Malaspina Glacier. Portions of its surface form a good highway to some of the coal camps in the east end of the Bering River coal field, but most of it is so covered by irregular masses of rock and gravel and so much crevassed that travel over its surface is difficult and dangerous.

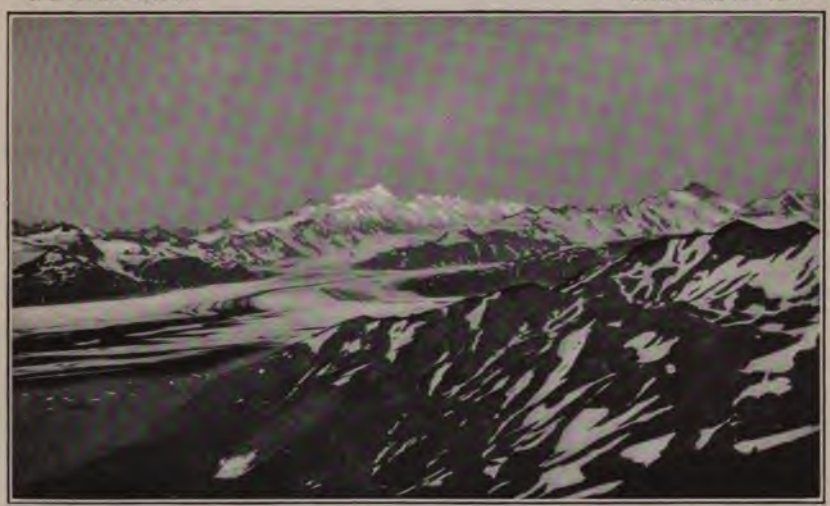
Martin River Glacier, which lies north of the coal field, is intermediate in size and character between Bering Glacier and the typical valley glaciers. It is formed by the union of several valley glaciers, which come out from the high mountains (see Pl. IV, *A*), and expand into a bulb-shaped terminus on reaching low ground. Much of its surface is deeply buried by moraine and is flat, but most of it is deeply crevassed. Two lobes of this glacier extend into the valleys occupied by Kushtaka Lake and Lake Charlotte. The former is known as Kushtaka Glacier.

Several small glaciers occupy positions on the colder slopes of higher mountains within the area here described. The largest of these is in the east end of the coal field and is known as Slope Glacier. Three very small ones are near it, and an unknown number of small glaciers of various sizes occupy the high valleys on the west slopes of Ragged Mountain.

STREAMS.

The streams of this region have their supply partly from local rainfall and partly from the melting of the glaciers. Both sources are large, and the streams are all of great volume in proportion to their length and are subject to severe floods.

Bering River drains the greater part of the region. This stream has its source in lakes on the margin of Bering Glacier. (See Pl. VI, *A*, p. 46.) It flows southwestward for about 12 miles until it approaches Bering Lake, where it spreads into a broad delta. The water passes in part through the delta without entering the lake, and in part into the lake and out again at its southeast corner, where the river is reunited and flows southward for 8 miles to the northeast corner of Controller Bay. The lower course of Bering River is tidal, the current running in both directions at rates of 3 to 5 miles per hour with the tide. The water of Bering Lake has a rise and fall of 1 to 3 feet. Bering River above the lake is nontidal, the current running from 8 to 10 miles per hour in the upper part and about 3 miles per hour in the vicinity of the lake. The tributaries of Bering River above the lake include Canyon Creek, which has its source on the southern margin of Martin River Glacier; Stillwater



A. CHUGACH MOUNTAINS AND MARTIN RIVER GLACIER FROM MONUMENT MOUNTAIN, LOOKING NORTHEAST.

B. VOLCANIC PLUG AT THE SOUTH END OF KAYAK ISLAND.

Creek, which drains Lake Kushtaka and receives a large part of its supply from the Kushtaka lobe of Martin River Glacier; and Shepherd Creek, which drains Lake Charlotte and several other small lakes on the margin of the same glacier. The chief tributaries below the lake are Gandil and Nichawak rivers, which drain parts of the margin of Bering Glacier.

The other streams include Campbell and Edwardes rivers, which rise on the southwest margin of Bering Glacier and enter the east shore of Controller Bay; Katalla River, which rises in the hills west of Bering Lake and flows into Katalla Bay; and several of the headwater tributaries of Martin River. The latter rises on the western margin of Martin River Glacier and in Tokun Lake, and flows westward until it reaches the east edge of the Copper Delta. The waters there divide, part entering the delta of the Copper, and part flowing along the edge of the mountains close to the delta and entering the tidal sloughs behind Softuk Bar.

CLIMATE.

Few meteorologic observations have been made at points within the region here described, and so the following discussion is partly based on the records at neighboring stations, supplemented by the writer's general knowledge of weather conditions during the summers of 1903 to 1906, inclusive.

The following local meteorologic records were made and have been furnished by the Katalla Company:

Temperature, cloudiness, and precipitation at Katalla, 1907.

	Temperature (°F.).			Cloudiness (number of days).				Precipitation (inches).		
	Maximum.	Minimum.	Mean.	Clear.	Partly cloudy.	Cloudy.	Rain.	Rain.	Snow.	Total.
January	42	4	19.0	24	2	5	7	No record.		
February	36	2	23.5	13	2	13	13	No record.		
March	35	4	23.1	14	9	8	11	No record.		
April	50	23	35.8	8	10	12	12	7.5	2.0	--------
May	67	30	44.2	11	6	14	17	4.85	--------	4.85
June	80	41	50.0	6	9	15	16	8.29	--------	8.29
July	78	42	55.0	1	8	22	23	14.95	--------	14.95
August	84	44	59.4	5	11	15	17	11.41	--------	11.41
September	76	37	52.0	8	11	11	19	12.34	--------	12.34
October	54	22	41.7	1	7	23	29	25.52	1.25	25.62
November	52	20	34.4	3	9	18	23	11.44	15.5	12.44
December	44	4	32.0	5	7	19	23	10.2	15.75	11.48
The year	84	2	39.2	99	91	175	210	--------	--------	[a]101.38

[a] Eight months.

The nearest stations at which meteorologic records have been made are Orca, 45 miles to the northwest; Nuchek, 70 miles to the west; Fort Liscum, 90 miles to the northwest, and Sitka, 400 miles to the southeast of Katalla.

All of these stations, as well as the region here described, are included in what Brooks and Abbe[a] have designated the "Pacific coast

[a] Brooks, A. H., and Abbe, C., jr., General climatology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 148-149.

climatic province," which is characterized by heavy rainfall and cloudy weather and by moderate winter and low summer temperatures. General conditions throughout the province are well illustrated in the following tables,[a] giving the temperatures and rainfall at Orca, Nuchek, Fort Liscum, and Sitka:

Temperature (°F.) at stations nearest Controller Bay.

	Maximum.				Minimum.				Mean.		
	Sitka.[a]	Nuchek.[b]	Orca.[c]	Fort Liscum.[d]	Sitka.[a]	Nuchek.[b]	Orca.[c]	Fort Liscum.[d]	Sitka.[a]	Orca.[c]	Fort Liscum.[d]
January	51	48	49	45	−2	20	5	−14	34.2	25.9	23.8
February	54	47	45	42	−3	16	8	−12	33.0	30.1	15.5
March	65	45	61	52	−1	27	2	−8	37.2	34.5	30.8
April	70	54	70	52	19	27	25	2	41.9	40.0	31.6
May	80	54	72	62	28	30	28	25	46.9	44.8	39.4
June	80	70	83	79	33	39	35	32	51.6	52.4	49.6
July	87	69	90	77	35	47	33	32	54.4	57.6	50.5
August	82	70	80	70	39	46	40	30	56.6	55.8	46.6
September	74	.....	84	64	32	.....	30	25	52.3	52.2	.....
October	67	65	64	58	25	22	25	18	45.7	40.3	.....
November	59	45	48	45	5	10	11	0	39.8	31.8	22.4
December	59	41	47	41	7	13	7	−13	35.0	29.4	21.6
The year	87	70	90	79	−3	10	2	−14	44.5	41.2	.....

[a] November, 1867, to May, 1877; April, 1881, to September, 1887; July, 1898, to February, 1899; May, 1899, to December, 1902.
[b] October, 1883, to August 31, 1884.
[c] Broken record from June, 1899, to October, 1905.
[d] January, 1901, to December, 1902.

Precipitation at stations nearest Controller Bay.

	Number of days with rain exceeding 0.01 inch.				Rainfall (including melted snow), inches per month.			
	Sitka.[b]	Nuchek.[c]	Orca.[d]	Fort Liscum.[e]	Sitka.[b]	Nuchek.[c]	Orca.[d]	Fort Liscum.[e]
January	16.8	23.0	14.0	17.5	12.17	27.07	12.58	9.67
February	15.9	8.0	9.7	5.0	7.47	9.15	7.49	1.01
March	18.0	21.0	16.7	14.5	6.70	18.02	18.69	5.54
April	12.6	18.0	14.7	9.0	5.61	16.92	12.70	4.50
May	16.1	18.5	18.0	9.0	4.17	18.92	12.06	2.26
June	13.6	10.5	10.7	8.0	3.31	4.17	5.55	0.68
July	14.9	18.5	10.8	14.5	3.55	9.93	4.65	4.21
August	16.8	13.0	14.8	28.5	5.84	14.13	14.35	12.38
September	19.5	19.0	14.5	22.5	9.67	22.96	15.26	14.22
October	21.7	22.0	21.2	22.0	11.96	21.50	21.53	14.25
November	19.6	13.0	13.0	11.5	9.80	10.51	9.97	6.63
December	18.9	19.0	14.7	13.0	7.84	16.81	14.52	5.95
The year	207.9	203.5	172.8	175.0	88.10	190.09	149.33	81.33

[a] Compiled from reports of voluntary observers of the weather bureau of Alaska as published in the reports of Prof. C. C. Georgeson on agricultural investigations in Alaska.
[b] November, 1867, to May, 1877; April, 1881, to September, 1887; July, 1898, to February, 1899; May, 1899, to December, 1902.
[c] October, 1883, to August 31, 1884.
[d] Broken record from June, 1899, to October, 1905.
[e] January, 1901, to December, 1902.

Monthly temperature and precipitation at Orca from June, 1899, to October, 1905.

	Temperature (° F.).					Precipitation.	
	Extremes for term of record.		Averages by months.				
	Maximum.	Minimum.	Maximum.	Minimum.	Mean.	Days with rain or snow.	Amount (inches).
January, 6 years	49	5	44.0	11.2	25.90	14.0	12.58
February, 6 years	45	8	41.3	16.3	30.07	9.7	7.49
March, 5 years	61	2	53.0	12.0	34.47	16.7	18.69
April, 8 years	70	25	64.0	27.3	40.04	14.7	12.70
May, 2 years	72	28	68.0	29.0	44.81	18.0	12.06
June, 2 years	83	35	80.0	36.0	52.35	10.7	5.55
July, 3 years	90	33	83.0	40.7	57.63	10.8	4.65
August, 4 years	80	40	76.25	41.5	55.83	14.8	14.35
September, 5 years	84	30	75.0	34.8	52.23	14.5	15.26
October, 6 years	64	25	56.3	28.8	40.30	21.2	21.53
November, 6 years	48	11	46.0	20.0	31.78	13.0	9.97
December, 6 years	47	7	45.2	13.0	29.43	14.7	14.52
Term of record	90	2					
Average for year					41.24		
Total for year						172.8	149.33

These tables show a maximum of precipitation and of winter temperature and a minimum of summer temperature on the seaward border of Prince William Sound in the vicinity of Nuchek and Orca. The precipitation becomes gradually less and the range of temperature greater away from the open sea, as is shown by the very much decreased rainfall and the slightly cooler summer and much colder winter temperatures at Fort Liscum. In the direction of Sitka the change consists of a decrease in rainfall, with higher summer and lower winter temperatures.

The climatic conditions on Controller Bay probably differ little if any from those at Orca and Nuchek. The rainfall is enormous, possibly even rivaling that at Nuchek and Orca, where there are records of 198 and 143 inches of precipitation in single years. May and June are sometimes, but not always, somewhat drier than the rest of the summer. There is almost invariably clear weather with and following a west or southwest wind, and rainy weather with an east wind. The severe storms all blow from the east and northeast.

VEGETATION.

The vegetation of this region is closely related to its topographic features. The three following types may be recognized:

Swamps and meadows: These are developed upon the alluvial flats and their growth consists predominately of grass and small bushes. Trees are restricted to willow and cottonwood on the borders of the watercourses, and spruce and hemlock on the drier sandy places, such as abandoned beaches and watercourses.

Evergreen forests: Spruce and hemlock predominate in the denser forests, which are located on the lower slopes of the hills and moun-

tains. They extend from the edges of the alluvial flats to an elevation of 800 to 1,000 feet, where they begin to gradually thin out. The interspaces between the groups and areas of trees, which widen toward the higher altitudes, are filled with grass and with dense thickets of alder and willow. The general upper limit of the forests is at an altitude of about 1,200 feet, and the extreme upper limit of good trees is 1,700 feet. The trees on the lower slopes are very large and densely spaced, and the quality of the lumber is fair.

Mountain-top vegetation: The upper slopes and summit of the hills and mountains above the tree line, as defined above, are partly bare (see Pl. IV, *A*, p. 16) and partly covered with grass, small herbs and bushes, and stunted alders and spruce. It is worthy of note that vegetation of this type descends far lower in this region than is usual in this latitude. The importance of this characteristic lies in the fact that it restricts the area of valuable timber and affords easy travel in considerable areas above timber line.

SETTLEMENTS.

The post-office and chief trading center for the entire Controller Bay region is Katalla, which is situated on the shore of Katalla Bay and is now the landing place of the steamers. Chilkat, near the mouth of Bering River, is a mixed settlement of whites and natives and is a stopping place on the way up the river to the coal field. The town of Kayak, on Wingham Island, which was formerly a post-office and steamer landing, is now practically abandoned. There are no other settlements except the camps of the various coal and oil companies, which are scattered throughout all parts of the region.

TRANSPORTATION.

EXISTING FACILITIES.

The only communication with other regions is by water. Katalla is a regular stopping place for steamers from Seattle to Valdez and Seward, there being five or six boats a month. The voyage from Seattle to Katalla requires three and a half to four days "outside route" or seven to eight days "inside route" via Juneau. The nearest large towns are Juneau, which is from two to three days' journey to the east, and Valdez and Seward, which are from ten to eighteen hours and from twenty-four to thirty-six hours, respectively, to the west. There are telegraph and cable offices[a] at these towns. Valdez and the other Prince William Sound ports can also be reached by crossing the Copper Delta in a small boat to Orca, a two-day journey, from which place there is regular and frequent communica-

[a] Plans are also under way to connect Katalla with the existing cable.

tion with Valdez and the other Prince William Sound towns by launches, in addition to the ocean-steamer service.

There is regular transportation of passengers and freight from Katalla to all parts of Controller Bay and to Bering Lake by launches, and much of the rest of the region is accessible by means of canoes. Bering River as far as the mouth of Canyon Creek, Stillwater Creek, Shepherd Creek, Gandil, Nichawak, and Katalla rivers, and others of the larger streams are navigable for canoes and poling boats. Most of the local transportation is consequently effected in this way.

Land travel is not practicable except where trails have been built, because of the dense vegetation, the swampy character of the flats, and the large number of streams. Most of the trails are indicated on the maps (Pls. II, V, VIII). The most important of these trails include those from Katalla to Mirror Slough, from Katalla along the beach to Strawberry Harbor and to the head of Katalla Slough, from the mouth of Bering River to the head of Katalla Slough (which is practically a well-built wagon road), from the mouth of Dick Creek to Lake Tokun, from Canoe Landing up Shepherd Creek to Lake Charlotte with a branch from Carbon Creek across Kushtaka Ridge to Kushtaka Lake, from Canoe Landing direct to Kushtaka Lake, from the mouth of Stillwater Creek to Lake Kushtaka with branches up Clear and Trout creeks, from the mouth of Stillwater Creek up Canyon Creek, and across Carbon Mountain to First Berg Lake. From this last point the shores of Berg Lakes (see Pl. VI, *A*, p. 46) and a portion of the surface of Bering Glacier affords a highway into all the valleys opening on the lobe of Bering Glacier, which borders the five Berg Lakes. Other shorter trails reach practically all the camps which are not accessible by water. Short tramroads have been built from the head of Katalla Slough and from the mouth of Redwood Creek to neighboring oil wells and from Canoe Landing to a coal opening.

RAILWAY ROUTES.

Reference has already been made (p. 15) to the railway surveys which have hitherto been made or which are in progress. The object of these proposed roads is to make the Bering River coal accessible for shipment, or to provide a route [a] to the copper deposits and other resources of the Copper River region, or both. The conditions which will govern the selection of the route include the character of the harbor at the terminus, the cost of construction and operation of the road, and the prospective freight tonnage.

[a] Brooks, Alfred H., Railway routes: Bull. U. S. Geol. Survey No. 284, 1906, pp. 10-17; Railway routes in Alaska: Nat. Geog. Mag., 1907, pp. 16-190.

HARBORS.

The harbors which have been considered by the various interests purposing to build a railroad include Controller Bay, Katalla Bay, the shelter afforded by Fox and Whale islands, and Orca Bay.

Controller Bay gives good shelter for large vessels, but is often too rough for small boats. The anchorage is good and the channel deep, but the deep water is a long distance from shore. The broad shoals which border the bay on the north and east sides, the lack of shelter for small boats in the steamer anchorage, and the fact that the bay is more or less filled with ice in severe winters all count against Controller Bay as a railway terminus, although its use is admitted to be possible.

Katalla Bay has sufficient depth of water, good anchorage, and is entirely free from ice in all seasons. It is open between the south and southwest, but has good shelter from the north and east. Inasmuch as all severe storms come locally from the east and northeast, it is claimed by many that Katalla Bay in its present condition is a good harbor and that steamers could tie to wharves in it under all conditions. The deep-water anchorage is not safe for small boats in bad weather, but Katalla River and Slough give perfect shelter and can usually be entered at high tide by anything drawing less than 10 feet, although the bar is often dangerous for open boats except at flood tide. Plans have been made to build breakwaters which will give shelter from all directions at the proposed wharves.[a] Katalla Bay is perfectly practicable as a harbor, provided that severe storms do not come from the southwest or west, or that breakwaters can be built at reasonable cost.

Fox and Whale islands give good shelter except from the southwest and west, and have deep water close to the islands. The proposed plan[a] is to connect Whale Island with the mainland by a causeway (this interval is dry at half tide) and to build wharves from the west shore of Whale Island. A further suggestion is to build breakwaters connecting Whale and Fox islands and westward from the latter. This proposition is similar to that at Katalla Bay, except that deep water is nearer shore at the islands, but the area of natural shelter is smaller. Here, as at Katalla Bay, it is a question of safety from possible southwest storms and of cost of breakwaters.

Orca Bay is a good harbor, being large, deep, and perfectly sheltered. No harbor improvements would be necessary, except buoys and wharves. Its disadvantage as a harbor lies in its distance from the open sea, the entrance being around Cape Hinchinbrook (see Pl. I). As far as its possible use as port for the Controller region is concerned, it has the further disadvantage of distance by rail. This point will be discussed later (pp. 23–24).

---

[a] Work was begun on this project in 1907.

ROUTES.

The possibilities of railway construction from any of the above-mentioned local harbors to the Bering River coal fields are well shown on the accompanying topographic map (Pl. II, pocket), and are also indicated by the lines of levels represented by the list of bench marks on page 13.

It can readily be seen from the map that grades are insignificant and that the only problems will be those connected with ballasting and bridges. The broad alluvial flats are swampy and are underlain by muck, consequently much ballast and ditching will be necessary.

A road from either harbor [a] in the vicinity of Katalla to the coal field will naturally follow the broad valley of Katalla River, cross the 65-foot (more or less) divide to Bering Lake, and trestle or fill across Bering Lake (which barely exceeds 5 feet in greatest depth and is for the most part much shallower). The bridges over Shepherd, Stillwater, and Canyon creeks will be small, but severe floods must be allowed for in building abutments.

If Controller Bay is used as the harbor the wharves might be built either from the south end of Kanak Island or from the east shore of the bay. In the former case a long bridge must be built to the mainland. The road could then go by the Katalla River route already described. From wharves on the east shore of the bay the road would naturally cross the flats on the east side of Bering River to a point opposite Shockum Mountains. A large amount of ballasting would be necessary on these swampy flats unless the road is located well to the east, where the flats are made up in part of sand and gravel. Many bridges, most of them small, would be required, the largest being over Bering River.

A railway from this region into the interior would either go west from Katalla along the ocean shore and up the east side of the Copper delta, or would go up Shepherd Creek (see Pls. I and II), over the 350-foot pass northwest of Lake Charlotte, and down the valley of Martin River to the Copper. Neither will encounter great difficulties until the site of the proposed [b] Copper River bridges, at Miles and Childs glaciers, is reached. The construction of bridges over glacial streams must always be a problem.

The route from Orca [c] to the coal field follows the foot of the mountains on the west side of Copper Delta until the bridge site, mentioned above, is reached. It would then follow the route, described above, from Copper River to the coal field. The disadvantages of this route consist in its length and its crossing Copper

[a] A railroad from each of these harbors was begun in 1907.

[b] Brooks, Alfred H., Railway routes: Bull. U. S. Geol. Survey No. 284, 1906, pp. 13-15; Railway routes in Alaska: Nat. Geog. Mag., 1907, pp. 182, 190.

[c] Construction was begun on a railroad from Cordova, a new town situated near Orca, in 1906.

River. A road from Orca to the interior[a] would cross Copper River twice, while one from a local harbor would cross it but once to reach the interior.

All the plans considered above are possible, and the choice must depend on questions of cost, including both the actual cost of operating the road and the interest on the original investment. There are no difficulties connected with building a railroad from any point on Controller Bay or Katalla Bay to the coal field, and the projects for a road from Orca to the coal field or from either terminus into the interior present no greater difficulties than have been overcome elsewhere. The important factors in the problem are, on one hand, the relative merits of a local harbor, questions of depth of water, holding ground, shelter from storms and from ice, and cost of improvements being considered; and, on the other hand, the cost of a longer road to a possibly better harbor farther west.

GEOLOGY.

GENERAL FEATURES.

The general succession of rocks in this region is shown in the following table:

General section of rocks of the Controller Bay region.

Age.	Formation name.	Character of rocks.	Thickness.
			Feet.
Quaternary.		Stream deposits, probably in part underlain by marine sediments.	0–500 +
		Sediments and abandoned beaches of glacial lakes.	0–200 +
		Morainal deposits.	0–100 +
		Marine silt and clay.	100
Tertiary or later.		Diabase and basalt dikes.	
Tertiary	Tokun formation.	Sandstone.	500
		Shale.	2,000 +
	Kushtaka formation.	Arkose with many coal beds.	2,500 +
	Stillwater formation.	Shale and sandstone.	1,000 +
	Katalla formation.[b]	Conglomerates, and sandstones and shales, some of which are conglomeratic.	2,500
		Sandstone.	500
		Shale, concretionary and with a glauconitic bed at the base.	2,000
		Sandstone.	1,000
		Shale.	500 +
Pre-Tertiary.		Graywacke, slates, and igneous rocks.	

[a] Brooks, Alfred H., loc. cit.

[b] The position of the Katalla formation with reference to the other Tertiary formations *is not definitely* established. See discussion on pp. 37–41.

As the surface of the country is about equally divided between flat lowlands and hilly districts, so also the area of rock is equally divided between unconsolidated alluvial deposits and indurated complexly folded rocks. The geologic features in this respect exactly coincide with the topographic features, the hard rocks being entirely restricted to the hilly areas and the alluvium to the flats.

The hard rocks, except two areas of metamorphosed pre-Tertiary deposits and the dikes, are Tertiary sediments largely of marine origin. They have been completely indurated, and involved in complex structural disturbances in which close folding and faulting of diverse character have taken part. Igneous intrusion has taken place, but has played a small part. Both the intensity of the folding and the abundance of dikes are greatest in the northeast part of the district toward the high mountains.

NEIGHBORING PROVINCES.

As this province is topographically a foothill region on the edge of the Chugach Mountains, so in its stratigraphy and structure it partakes of the general geologic conditions bordering that mountain range.

The Chugach Mountains [a] consist of closely folded slates, schists, and gneisses, with large intrusive masses of granitic rocks. The detailed structure and stratigraphic succession are not known. In the Prince William Sound region the rocks consist of two metamorphosed sedimentary groups,[b] the Valdez "series" and the Orca "series," of undetermined but probably Paleozoic age. The latter is associated with greenstones derived from basic lava flows. Granitic masses and other intrusives are represented. In the Mount St. Elias-Yakutat Bay region [c] the rocks composing the high mountains comprise crystalline rocks, including schists and gneisses of undetermined but probably early Paleozoic age, granitic intrusives, slightly altered sedimentary rocks (Russell's "Yakutat system") of disputed age, but probably Mesozoic or late Paleozoic, and late Tertiary or post-Tertiary sediments (Russell's "Pinnacle system").

---

[a] Brooks, Alfred H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 29–32, 227–228, 253–256. Schrader, F. C., and Spencer, Arthur C., The geology and mineral resources of a portion of the Copper River District, Alaska. A special publication of the U. S. Geol. Survey, 1901, pp. 32–39.

[b] Schrader and Spencer, op. cit. Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, pp. 79–80.

[c] Russell, I. C., Nat. Geog. Mag. vol. 3, 1890, pp. 130–131, 140, 167, 170; Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 24–26, 34, 52, 90. Novarese, Inge Vittorio, Rocks and minerals of south Alaska: The ascent of Mount St. Elias, Appendix E, 1900, pp. 232–239. Tarr, R. S., The Yakutat Bay region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 61–63; Glacial geology and physiography of the Yakutat Bay region with a chapter on the bed-rock geology (in press). Blackwelder, Eliot, Reconnaissance on the Pacific coast from Yakutat to Alsek River: Bull. U. S. Geol. Survey No. 314, 1907, pp. 82–87.

The nature of the rocks in that part of the mountain belt which lies immediately behind the Controller Bay region is not known, except as the glaciers bring out fragments of a variety of granitic rocks, schists, gneisses, and greenstone.

The character of the contact of the rocks of the high mountains with those of the lower coastal belt is known only in Yakutat Bay region, where Russell and Tarr report the coarse crystallines as separated from the sedimentary rocks south of them by a fault. At the base of Mount St. Elias the crystallines are overthrust upon the younger rocks. The contact has not been studied between Mount St. Elias and Copper River, as most of the region has not been visited, while in the vicinity of Controller Bay the contact lies beneath glaciers. On Prince William Sound the high mountains run out into the sea and the coastal foothills are absent.

The Tertiary rocks of the Controller Bay region extend eastward beneath Bering glacier, and similar beds appear on the coast half way between Controller and Yakutat bays at Cape Yaktag, where gently folded shales and sandstones have been described[a] as outcropping in an anticline near and parallel to the coast.

DESCRIPTION OF THE ROCKS.

PRE-TERTIARY.

The metamorphic rocks of the Controller Bay region outcrop in two areas. One of these covers all of Wingham Island except the narrow southeast point. The other is west of Katalla in Ragged Mountain and in the low hills between it and the Copper Delta. The rocks consist of black slates having well-developed cleavage, graywacke, chert, a variety of highly colored fine-grained rocks of uncertain origin, and greenstone and other igneous rocks which probably include both bedded and intrusive masses. The observed contacts with the Tertiary rocks are faults, and these rocks are probably in both areas overthrust upon the Tertiary sediments.

The amount of metamorphism which these rocks have undergone as compared with the Tertiary rocks, which though in direct contact with them are entirely unmetamorphosed, proves a much greater age for the former and a great unconformity between them and the Tertiary rocks. The only fossils which have been discovered are numerous but poorly preserved *Globigerina* indeterminate species. The occurrence of *Globigerina* (assuming that the lower range of *Globigerina* has been finally determined) shows the rocks to be post-Carboniferous.

[a] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 264. Martin, G. C., The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 26-27; The Cape Yaktag placers: Bull. U. S. Geol. Survey No. 259, 1905, pp. 88-89.

while the degree of metamorphism shows them to be pre-Miocene. More definite evidence of their age is lacking.

The lithologic similarity of these older rocks to certain rocks at Orca,[a] Kodiak,[b] and Yakutat Bay,[c] is suggestive of a possibly corresponding age.

The correlation[d] of the rocks at Orca, Kodiak, and Yakutat is, in the writer's opinion, not positively established, while their reference[e] to the Lower Jurassic is based upon evidence which he regards as both insufficient and open to a different interpretation from that which has been drawn from it. The weight of the existing evidence concerning the age of the slaty rocks of the coast of the Gulf of Alaska from Yakutat to Kodiak is, in the writer's opinion, that they are almost certainly older than the Upper Triassic, and are probably, in part at least, late Paleozoic. The fragmentary evidence on the age of the slate and graywacke of the Controller Bay region suggests that these, too, may belong in the same general stratigraphic position.

TERTIARY.

KATALLA FORMATION.

DESCRIPTION.

The Katalla formation occupies the hilly area south of Bering Lake between Bering and Katalla rivers and the low hills between the base of the steep eastern slope of Ragged Mountain and Katalla River. Rocks which are probably, in part at least, equivalent to these outcrop in Gandil Mountain, Nichawak Mountain, Mount Campbell, and the neighboring small hills of the Nichawak region, on Kayak Island and on the southeast point of Wingham Island, in the low hills west of Bering Lake, and possibly in parts of the region north and northeast of Bering Lake.

The bulk of the formation is composed of soft, dark, argillaceous shales, in places with many limestone concretions and with at least one bed of glauconitic sand.

---

[a] Schrader, F. C., and Spencer, Arthur C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, pp. 33–40. Brooks, Alfred H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 225–230. Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, pp. 79–80.

[b] Brooks, Alfred H., loc. cit. Ulrich, E. O., Fossils and age of the Yakutat formation: Harriman Alaska Expedition, vol. 4, 1904, pp. 125–146.

[c] Ulrich, E. O., loc. cit. Brooks, Alfred H., loc. cit. Tarr, R. S., The Yakutat Bay region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 61–63; Glacial geology and physiography of the Yakutat Bay region, with a chapter on the bed-rock geology (in press). Blackwelder, Eliot, Reconnaissance on the Pacific coast from Yakutat to Alsek River: Bull. U. S. Geol. Survey No. 314, 1907, pp. 82–87.

[d] Emerson, B. K., Harriman Alaska Expedition, vol. 4, 1904, pp. 11–54.

[e] Ulrich, E. O., loc. cit.

Two[a] massive and prominent sandstones are present. One of these is at the top of the thickest and most prominent bed of shale. The other[a] is below the same shale, and is underlain by a bed of shale of the same character as the thicker shale above it.

The upper sandstone is overlain by conglomerates, sandstones, and shales, apparently of great thickness. The conglomerates, though massive, are of irregular extent and position, and grade locally into pebbly sandstone or shale, or lose their pebbles entirely. The more typical of the conglomerates contain usually well-rounded but unsorted pebbles of granite, greenstone, gneiss, and a variety of other rocks and minerals. The material ranges in size from that of very coarse sand up to a diameter of several feet, but is usually less than 6 inches in diameter. No glacial facets or scratches have been seen. The matrix consists of fine shale, sandstone, and arkose.

FOSSILS.

The following molluscan forms, obtained from the lower sandstone member, were determined by W. H. Dall:

From a prominent exposed rock just above the Chilkat Indian village on the west bank of Bering River: (4313) *Chionella*, *Cardium*, *Glycymeris*, *Macoma*, *Mya*, *Litorina*, and *Purpura*, too badly preserved to be specifically identified, but doubtless of Miocene age.

West shore of Bering River, just above Chilkat village: (4317) *Chionella*, *Macoma*, and *Acila*.

West shore of Bering River, one-half mile below Greene's cabin, or 1¼ miles above Chilkat: (4311) Young *Lunatia* (?).

West shore of Bering River, one-fourth mile below Greene's cabin, or 1½ miles above Chilkat: (4318) Fragments of extinct crab, starfish, echinoid, and ophiuran, and species of *Turbo* (?), *Isapis* (?), *Lunatia* (?), *Fusus* (?), a ribbed *Dentalium*, *Marcia* (?), *Chionella*, *Solen*, *Thracia*, *Mya*, *Periploma*, *Macoma*, *Acila*, and *Nucula*.

Bering River, west bank, 2 miles north of Chilkat: (4435) *Spisula* near *albaria* Conr., *Yoldia*, *Leda*, *Dentalium*, *Macoma* (?), *Angulus* (?), *Lunatia* sp., and indeterminable gastropods.

West bank of Bering River, opposite lower end of first island going upstream: (4320) *Macoma*, *Nucula*, *Leda*, and *Yoldia* sp. badly preserved; (4327) *Chionella* (?) in concretion; Miocene (?); (4314) *Phacoides* sp. and indeterminable gastropods.

Bluff on west bank of Bering River where the river flows from Bering Lake: (4315) *Scala*, *Neverita*, *Fusus*, *Chione* (?), *Phacoides*, *Spisula*, *Macoma*, and *Yoldia*.

Beach on south shore of Bering Lake, on first point west of its outlet: (4316) *Macoma*, *Neverita* (?); probably Miocene.

Split Creek, 100–200 yards above branch that heads against the Redwood Creek divide: (4323) *Pecten*.

---

[a] There is a possibility that the writer is in error in regard to the existence of two sandstones and that there is but one, which is on top of the shale, the apparent lower one, with its underlying shales, being a repetition of the upper sandstone and shale by faulting. The evidence on this point will be discussed under Age and correlation (pp. 37–41) and Structure (p. 44).

The following echinoderms were determined by W. B. Clark:

Gulch back of Greene's cabin, Bering River: (4119) *Asterias* sp. This specimen is evidently a species of *Asterias*, although some of the finer diagnostic characters are lacking. In general outline and other characters it closely resembles the species which ranges from the middle Mesozoic to the Recent and is a common form throughout the Tertiary.

West shore of Bering River, 1½ miles above Chilkat: (4318) *Schizaster* sp. There are many specimens of this form, and although again some of the finer diagnostic characters are absent I know of no other genus to which I could as satisfactorily refer it. I am inclined to think it belongs here. The range of this genus is from the Eocene to the present, and it is a common form throughout the Tertiary. It is very similar to a common undetermined species of *Schizaster* from the upper Eocene of the Gulf, of which I have a good number of specimens from localities in Mississippi. It is hardly probable that it is actually the same species, although it is closely related.

I should be inclined to regard the beds as Tertiary, possibly later Eocene or early Miocene in case there is other corroborative paleontologic evidence. I am sorry that the Echinoderm forms lack some of the essential features to make their determination sure. There is a bare possibility that the supposed *Schizaster* might be a rather unusual form of a simpler Spantangoid, either *Hemiaster* or a related genus, in which case the deposits might be pre-Tertiary as far as the Echinoderm evidence is concerned. The fasciole, which is an external character of the test, is so poorly preserved that I can not determine with certainty all of its characters, and for that reason there must be some doubt in the matter.

The following plants obtained from the lower sandstone were identified by F. H. Knowlton:

South shore of Bering Lake, 1 mile east of Sinclair's cabin: Aside from a few fragments of dicotyledons there is but a single complete leaf. This appears to be *Liriodendron Meekii* Heer, at least so far as size and shape go, but as there is no nervation preserved it is impossible to identify it positively. If it is this species, the age should be Upper Cretaceous, but if not, it is impossible to state.

Bering River, 1 mile above Chilkat Village: A single specimen representing the base only of a leaf. Apparently *Daphnogene Kanii* Heer. Age Kenai.

Gulch back of Greene's cabin, Bering River: A number of dicotyledonous leaves but poorly preserved. Seem to represent species of *Quercus*, *Betula*, etc., but impossible to be positive. The age is presumably Kenai.

Mollusks from the upper concretionary shale were identified as follows by W. H. Dall:

Mouth of Bering River, west bank, 100 feet east of waterfall: (4312) Miocene shales much crushed, containing species of *Chionella* (?), *Petricola*, *Thracia*, *Phacoides*, *Macoma*, *Thyasira*, *Yoldia*, *Acila*, *Neverita* (?), and *Buccinum*. (4436) *Phacoides*, probably *multilineata* Conrad, a large *Leda*, *Solemya*, *Limopsis*, *Dentalium*, some indeterminable gastropods, *Thracia ?*, *Petricola ?*, *Bela ?*, *Saxicava ?*, *Leda ?*.

Creek 1 mile below Greene's cabin, west bank of Bering River; elevation, 150 feet: (4328) Miocene shale with *Venericardia* near *ventricosa* Gould; a smooth *Dentalium* and species of *Bullaria*, *Lunatia*, *Mulinia* (?), and *Acila*, with fragments of crab.

West bank of Chilkat Creek, 2 miles above road: (4322) *Chrysodomus* (?), *Lunatia*, *Macoma*; probably Miocene.

Left bank of Burls Creek, ¾ mile south of a bare knoll and just opposite the mouth of two small streams that join as a fork just before emptying into Burls Creek: (4321) *Pseudamusium*, numerous but crushed so as to be indeterminable, and fragraments of Yoldia (?) Miocene (?).

Mitcher Creek, a tributary of Redwood Creek; elevation, 700 feet: (4326) Extinct crab in concretion.

Head of west fork of Arvesta Creek: (4325) *Pecten*, *Spondylus* (?), *Dentalium*, *Hemithyris*, and indeterminable coral recalling *Astrangia*.

The following mollusks from the upper sandstone and conglomeratic beds were determined by W. H. Dall:

Crest of ridge, 4 miles north of Point Hey: (4437) *Yoldia* sp. near *montereyensis* Dall.

Three-fourths of a mile northwest of Point Hey: (4324) Hard shale with fragments of *Neverita*, probably Miocene.

Near end of Point Hey: *Phacoides* (?) sp., *Callista* (?) sp., *Conus* sp., *Fusus* sp., A (medium), *Fusus* 2 sp. (small), *Turritella* sp., *Dentalium* sp. "Poor material, but the *Conus*, *Fusus*, and *Dentalium* look like Eocene forms."

Between Point Hey and Strawberry Point: *Astrodapis* (?) sp., *Semele* (?) sp., *Dentalium* sp.

South shore of Wingham Island: (4310) Small crab, of extinct species, and indeterminable species of *Solen*, *Macoma*, *Thracia*, *Leda*, *Yoldia*, and *Lunatia* (?). Probably Miocene.

Beach on northwest shore of Kayak Island. The signal station at south end of Wingham Island bears N. 8 E. (mag.): (4390 *Marcia* like *subdiaphana* (not in place).

Near cabin on Kayak lagoon, Kayak Island: (4391) Crushed specimen of elongated *Unio*.

The rocks exposed on the northwest shore of Kayak Island consist of beds of conglomerate, sandstone, and shale, with a marine fauna, in which W. H. Dall and Ralph Arnold have identified the following species: *Leda* sp. A. (smooth), *Yoldia* aff. *scissurata* Dall, *Yoldia* aff. *thraciaformis* Dall, *Macoma* cf. *calcarea* Gmel., *Callista* sp., *Natica* sp., *Chrysodomus* sp. A., *Chrysodomus* sp. B., *Rostellites* cf. *indurata* Conrad.

STILLWATER FORMATION.

DESCRIPTION.

The Stillwater formation occupies the entire valley of Stillwater Creek and extends for some distance up the valleys of Trout and Clear creeks, eastward to Canyon Creek, and westward probably throughout the entire area of Shockum Mountains. Other areas are on the northern and western shores of Berg Lakes, on the west shore of Kushtaka Lake, and in the mountain north of Bering Lake.

The formation consists of shale and sandstone without characteristic beds so far as is now known. No detailed sections have been measured, but the thickness apparently exceeds 1,000 feet. The base of the formation has not been recognized.

FOSSILS.

The following fossils were determined by W. H. Dall:

Maxwell Creek, east of Grade Trail and one-half mile south of Lake Charlotte: (4380) Fragment of a smooth *Dentalium;* apparently the same species as is found in the rocks above the coal.

Tributary of Clear Creek, about 1 mile northeast of Cunningham's warehouse; elevation, 275 feet: (4384) Same as 4377.

Stillwater Creek, east bank, one-half mile below Clear Creek: (4434) *Crassatellites? Spisula?*

Float in bed of Maxwell Creek, one-half mile below Lake Charlotte: (4385) *Mactra? Cardium? Lunatia?* (Same fossils as found above the coal, marine.)

East side of moraine at head of Lake Charlotte, one-fourth mile from lake: elevation, 510 feet: (4381) *Cyrene?* and *Anodonta?* (freshwater), *Fusus? Arca? Macoma? Mactra? Saxidomus?* and *Dosinia?* (marine), shark tooth.

Eastern edge of glacier moraine, 200 feet above the level of Lake Charlotte: (4379) Single valve, recalling *Clementia.*

Lower eastern tributary of Sheep Creek, 200 yards below waterfall, and 1 mile from Sheep Creek: (4393) *Fusus? Leda, Yoldia, Macoma? Mactra?*

Lower eastern tributary of Sheep Creek, one-half mile above the mouth of the creek (float specimens): (4387) *Dentalium, Lunatia? Fusus? Yoldia, Solen, Spisula? Dosinia?* (4392) *Dentalium, Buccinum? Fusus? Leda, Mactra,*

Head of Bering River, just below upper falls: (4397) *Fusus? Lunatia? Spisula?*

Bering River, one-fourth mile below gorge: (4394) *Fusus? Mactra?*

KUSHTAKA FORMATION.

DESCRIPTION.

The Kushtaka formation occupies part of the crest and much of the eastern slope of Kushtaka Ridge, and extends westward throughout the valley of Carbon Creek and up the east side of Shepherd Creek to Lake Charlotte. The largest known area extends in a broad belt from the eastern edge of Kushtaka Glacier to the northeast corner of the area mapped. There are two or more small areas in the southern part of Carbon Mountain. A large area lies on the north shore of Bering Lake and extends across the mountain from Shepherd Creek to Dick Creek. Another large area reaches from near the south end of Lake Charlotte to the east end of Lake Tokun and extends south on the mountain side for about 2 miles.

The Kushtaka formation overlies the Stillwater formation, probably conformably, although as the contacts are in many places faults the exact relations are none too well known.

It consists predominantly of coarse arkose, although some sandstone and much shale are present. It contains a large but unknown number of coal beds. Marine conditions are not known to be represented.

The thickness exceeds 2,000 feet, the exact total not being known. The following sections represent the upper part of the formation

and are probably characteristic in a general way of the entire thickness.

Section of upper part of Kushtaka formation in valley of Carbon Creek.

	Ft.	in.
Black shale (overlain[a] by Tokun formation).		
Coal		4
Dark blackish shale	9	
Coal		10
Dark blackish shale	15	
Coal		4
Dark blackish shales with several more or less carbonaceous layers	26	
Thin-bedded arkose with shale	26	
Sandy shale	86	
Arkose	535	
Sandy shale	141	
Arkose	27	
Sandy shale	35	
Flaggy and thin-bedded arkosic sandstone with thin calcareous beds	398	
Thin-bedded arkose sandstone	44	
Thin-bedded sandy shale with calcareous concretions	167	
Coal with shale; outcrop obscured, about 6 feet of clean coal estimated	14	2
Shale	25	
Carbonaceous shale	1	
Coal	2	8
Shale		4
Coal	1	11
Shale	1	
Sandy shale with concretions	84	
Carbonaceous shale, somewhat crumpled	2	
Sandy shale	20	
Carbonaceous shale	1	
Sandy shale (bluish)	34	
Coaly beds or carbonaceous shale	4	11
Sandy shale with calcareous concretions	39	
Base of section in bottom of Carbon Creek at an elevation of 1,250 feet, but the coal series continues on downward.		
	1,741	6

Section of Kushtaka formation on crest of Kushtaka Ridge.[b]

	Ft.	in.
Shale, carbonaceous (overlain by Tokun formation)		2
Shale		6
Coal (shaly at bottom for 1 foot)	3	2
Shale (dark, but weathers brownish red)	9	
Coal	4	8
Shale (dark, with some coal)	9	4

[a] See footnote, p. 35.

[b] The uppermost bed is 80 feet below U. S. L. M., Kayak No. 4.

	Ft.	In.
Shale, blue, sandy	48	
Arkose	231	
Shale, dark	9	
Shale, carbonaceous (with bands of coal 6 to 12 inches thick—exposure poor)	45	
Arkose, flaggy and fine-grained	93	
Shale, carbonaceous	2	
Coal	2	3
Shale, carbonaceous		5
Arkose, flaggy and fine-grained	127	
Fine-grained blue shale	291	
Coal (exposure not good, estimated with shale)	11	7
Shale	5	
Arkose, flaggy	41	
Shale	4	
Carbonaceous shale with coal (exposure obscure)	23	
Arkose, flaggy	163	
Shale, dark (with thin coal streaks ½-inch thick)	5	
Coal		6
Shale	1	
Coal		6
Shale	2	
Coal		5
Shale	9	
Arkose, flaggy	29	
Shale	2	
Shale, carbonaceous	5	
Arkose, flaggy	4	
Shale	14	
Arkose, flaggy	11	
Shale	7	
Coal	3	
Shale		6
Coal		6
Shale		6
Coal	1	
Shale	2	
Arkose, flaggy	36	
Shale	4	
Arkose, flaggy	24	
Shale, dark	2	
Coal, clean	8	
Shale, carbonaceous	1	
Shale	35	
Arkose, flaggy	77	
Shale	2	
Arkose, flaggy	74	
Shale, sandy	15	
Arkose, flaggy	25	
Shale, with coal streaks	5	
Coal	1	
Shale	2	
Coal, clean	5	

	Ft.	in.
Shale	287	
Arkose	130	
Shale	87	
Base of section at anticlinal axis on divide at head of Carbon Creek.		
	2,041	

Section of upper part of Kushtaka formation on southern end of Cunningham Ridge.

	Ft.	in.
Arkose, possibly with thin beds of coal	60	
Coal (5 to 6 feet thick with shale)	10	
Arkose	37	
Thin-bedded arkose	46	
Coal	1	
Thin-bedded shaly arkose	92	
Dark shale	29	
Coaly shale		5
Coal	1	
Dark shale with calcareous concretions	50	
Shale	1	
Coal		4
Shale		4
Coal	10	
Shale	1	
Coal	2	4
Shale	2	
Dark shale with concretions, several thin beds of arkose, and several beds of coal whose thickness could not be determined	153	
Thin-bedded arkose	33	
Dark shale	12	
Measurement stopped because of irregularity of the beds.		
	541	5

FOSSILS.

The following molluscan forms were identified by W. H. Dall:

Coal opening[a] near Grade Trail Cabin, 15 feet west of coal. (4386) *Mactra or Spisula? Nassa?*

The following plants were identified by F. H. Knowlton:

Grade Trail Cabin coal opening, along west contact of shale with coal:

Aralia sp. cf. *A. Jorgensi* Heer, dicotyledonous leaves, fragments of large leaves, stems. *Aralia Jorgensi* Heer is of Miocene age, and while the *Aralia* in this collection is not quite the same it is pretty close, and for this reason I should incline to regard the age as Miocene.

About 150 feet southwest of U. S. L. M., Kayak No. 4. One specimen with good outline but no nervation. Probably a *Sapindus*, or something of the kind. Not sufficient to determine age.

About 100 yards southeast of group of four small lakes, about 1¼ miles northeast of Lake Charlotte: Two specimens with fairly good outline, but no nerva-

[a] See section No. 66, p. 78, and Pl. VIII.

tion. Probably leaflets of some leguminous plant, but not sufficient to settle age.

Bed of creek flowing into head of Canyon Creek from Mount Chezum, at an elevation of 2,000 feet: *Dryopteris* sp. cf. *Pteris frigida* Heer, *Cornus* sp., *Juglans* sp. "*Pteris frigida*" is normally a Cretaceous species, but the particular specimen with which this is compared was from a Tertiary (Miocene?) horizon. The generic reference is undoubtedly wrong. The two dicotyledons mentioned are very modern in appearance, and on this insecure basis I should incline to regard the age as Miocene.

Lower eastern tributary of Sheep Creek, one-half mile above its mouth: A single broken specimen. Suggests *Andromeda grayana* Heer. The age is uncertain, but if this species is correctly identified it should be Kenai.

Elevation of 1,000 feet on creek emptying into First Berg Lake, where trail from Happy Hollow passes around the shore. *Dryopteris* sp., *Quercus* sp., *Ficus* sp., *Ulmus* sp., *Juglans* sp., *Cornus* sp. This material is ample in amount and beautifully preserved. The fern is a splendid species and appears to be new, as, indeed, do all the other forms. So far as I am able to determine, this is not Kenai in age, but just what the age is I am uncertain. I should think it ought to be Miocene, but without an extensive comparison with known Miocene floras its exact position is in doubt.

Lower eastern tributary of Sheep Creek, one-half mile above its mouth: *Quercus?* sp., *Ficus?* sp. Age unknown, possibly Kenai.

Near head of Bering River (float specimens collected by Prof. W. O. Crosby). *Salix* sp. cf. *S. varians* Heer, *Corylus Macquarrii* (Forbes) Heer, *Betula prisca* Ett., *Betula grandifolia* Ett.: These are well-known forms found in the so-called Arctic Miocene, and indicate this age for the beds whence they came.

TOKUN FORMATION.

DESCRIPTION.

The Tokun formation outcrops on both shores of Lake Tokun and extends thence north and northeast to the edge of the flats bordering Martin River Glacier and to Lake Charlotte. It also covers large areas on the crests and northwest slopes of Carbon and Charlotte ridges, on the west slope of Kushtaka Ridge, on the ridge north of Mount Hamilton, and on the northwest slope of Cunningham Ridge.

These beds overlie the Kushtaka formation conformably, the transition apparently representing a change from fresh-water to marine conditions. The formation is at least 2,500 feet thick, the lower 2,000 feet consisting chiefly of sandy shales, which are well shown in the following section:

Section of the Tokun formation[a] *on the crest of Carbon Ridge.*

	Ft.	In.
Sandy shale, poorly exposed, possibly more above	248	8
Sandy shale (top of this makes highest point of Carbon Ridge)	46	5
Fine shaly sandstone	17	5
Fine sandy shale	72	1
Sandy shale	139	5
Fine-grained shaly sandstone	40	4

[a] The section of the Kushtaka formation on pp. 32–34 underlies this without a break.

	Ft.	in.
Dark-gray fine-grained shales	135	11
Gray fine-grained shale with some thin sandstone and beds of calcareous concretions	163	2
Gray sandy shale	421	6
Fine sandy shale with some limestone beds	278	3
Arkose	285	6
Fine, gray, sandy shale	13	7
Arkose (coarse at base, fine-bedded at top)	150	10
Black shale, somewhat crumpled (underlain by the Kushtaka formation	5	
	2,018	1

The shales (not all of which are represented in the section) are overlain by a bed of sandstone several hundred (possibly 500) feet thick. This sandstone is well exposed on the hills northeast of Lake Tokun and west of Lake Charlotte. The beds overlying this sandstone contain some shale, but are not well exposed.

FOSSILS.

The following mollusks were identified by W. H. Dall:

One-half mile northeast of Summit Cabin, Kushtaka Ridge, 250 feet above large coal seam on Queen Creek and near the base of the Tokun formation: (4440) *Spisula, Fusus, Lunatia, Leda, Solen, Lucina* probably *multilineata* Conrad, *Molopophorus* sp.? (4378) Same as 4377, with the addition of the print of a large *Semele?*

Fine-grained flaggy sandstone with thin calcareous beds, 1,000 feet S. 60° E. of Queen coal opening; elevation, 1,600 to 1,700 feet. (4377) *Fusus* or *Latirus, Litorina? Nassa? Yoldia, Leda, Lunatia? Mytilus, Macoma, Solen, Mactra* or *Spisula*, and *Cytherea?* or some Veneroid form.

One-half mile northeast of locality No. 4440, on crest of Kushtaka Ridge (on the strike from locality No. 4440): (4441) *Leda, Yoldia? Spisula?*

Southeast edge of Kushtaka Glacier, about 1¾ miles from Kushtaka Lake; elevation, 350 feet: (4382) Fragments of the arms of an ophiuran.

Southeast edge of Kushtaka Glacier, about 2 miles from Kushtaka Lake; elevation, 480 feet: (4383) *Haminea* or *Bullaria, Yoldia*, and *Macoma.*

Gap between Mount Chezum and Monument Mountain: (4395) *Fusus? Lunatia? Mactra* or *Spisula?*

One-fourth mile northeast of Mount Chezum, in deep canyon: (4438) *Lunatia, Diplodonta? Dentalium, Fusus, Spisula, Mactra? Macoma?*

Middle fork of Trout Creek near its head: (4396) *Fusus?* fragm. of bivalves.

UNDIFFERENTIATED TERTIARY.

The areas represented on the map (Pl. V, pocket) as undifferentiated shale and sandstone probably consist predominantly of the rocks of the Katalla formation, except on the south end of Carbon Mountain, where they represent either the Stillwater, Kushtaka, or Tokun formations. These areas are those in which the geologic work was not finished with sufficient detail to show the boundaries of the formations.

AGE AND CORRELATION.

The Tertiary sediments, as shown in the preceding pages, consist of monotonous repetitions of shales and sandstones, with an included mass of coal-bearing arkose and one or more massive conglomerates. The total thickness, as shown in the following table, is many thousand feet. The structure of the region in which these rocks outcrop is complex; exposures at critical points are often wanting; and neither the lithologic character of the beds nor the fossils which they contain are sufficiently distinctive to make it possible to recognize with certainty the complete stratigraphic succession.

The presence of two easily recognized horizons, the arkose and the conglomerate, give distinctive character to two parts of the stratigraphic column. The arkose, with its associated coal, is restricted in areal distribution to the region north of Bering Lake, and the conglomerate to the region south of the lake. Between these regions are areas of no outcrops, and none of the beds of either region can be recognized with certainty in the other.

Section north of Bering Lake.

			Feet.
Tokun formation.	*a.*	Sandstone	500
	b.	Shale with thin, flaggy sandstones and with occasional calcareous concretions	2,000+
Kushtaka formation.	*c.*	Arkose with many coal beds and with some shale and sandstone	2,500±
Stillwater formation.	*d.*	Shale and sandstone	1,000+

Section south of Bering Lake.

Katalla formation.	*e.*	Conglomerate and conglomeratic sandstones interbedded with shale and sandstone	2,500
	f.	Flaggy sandstone	500±
	g.	Soft shale with calcareous concretions and with bed of glauconitic sand near base	2,000
	h.	Sandstone	1,000
	i.	Soft shale	500+

The succession in each of these sections may be assumed as reasonably correct, although there is a possibility that the thicknesses are too great because of there having been repetition of the less characteristic beds by faulting. The correlation of the beds of one section with those of the other rests at present upon evidence which is incomplete and unsatisfactory, and must be regarded as suggestive rather than conclusive. It is probable that one of two correlations is true: The shale and sandstone of the Stillwater formation (*d*) may overlie the conglomerates (*e*) of the Katalla formation with a concealed interval of unknown extent between them, or *a* and *b* may be identical with *h* and *i*. In the former case the conglomerates underlie the coal field; in the latter case the coal underlies all, or nearly all, of the entire

region under discussion. The stratigraphic and structural field evidence proves nothing either way, but suggests, as the most probable relation, that the entire section north of Bering Lake overlies the section south of the lake.

The Tertiary rocks contain fossils at many localities, but they are usually poorly preserved or not characteristic. They consist chiefly of leaves and of marine Mollusca, but include also a few echinoids, Crustacea, fish, and fresh or brackish water Mollusca.

The strata and localities which yielded the more important fossils are as follows:

1. Sandstones of the lower part of the Tokun formation, yielding abundant marine Mollusca at several localities.

2. Arkose and coal beds of the Kushtaka formation, yielding fossil leaves at many localities.

3. Shales and sandstones of the Stillwater formation, yielding poorly preserved Mollusca of both marine and fresh-water types.

4. Shale and sandstone associated with conglomerates at localities on Kayak Island and elsewhere, yielding marine Mollusca. The localities on the mainland are in the upper part (*e*) of the Katalla formation. The conglomerates on Kayak and Wingham islands are correlated with the other conglomerates on purely lithologic evidence.

5. Sandstone (*f*) underlying the conglomerate of the Katalla formation, yielding a few marine fossils.

6. Soft shales (*g*) of the Katalla formation, yielding marine Mollusca, Crustacea, and fish.

7. Lower sandstone (*h*) of the Katalla formation, yielding marine Mollusca and echinoids at several localities on the banks of Bering River and elsewhere.

Dr. W. H. Dall, after examining the fossils collected in 1905 in the region north of Bering Lake from the Tokun and Stillwater formations, said:

In regard to the fossils themselves it should be premised that they consist of crushed and distorted shells in a very tough and hard matrix which wholly conceals the muscular impressions and hinges of bivalves, and the aperture and pillar of gasteropods, so that in most cases even the genus is uncertain, and in the present state of our knowledge it is impossible to make specific identifications. Hereafter when we shall know the Tertiary faunas of the Pacific coast thoroughly it may be possible to identify several of these species, but not till then.

I may add that there are no characteristic Eocene or Miocene types in the specimens collected; that the fauna below the coal appears to be identical with that above it; that the *Marcia* and *Clementia* point in the direction of Oligocene age; that the mixture of fresh water and salt water forms indicates a location near salt water but with fresh water near by, as in a river delta. I may express the suggestion that the fauna is marine Oligocene corresponding to the marine phase of the Kenai group, hitherto unknown. It is certainly not Eocene, and if Miocene, not the same fauna as the Astoria or Coos Bay (Empire beds)

Miocene fauna, and apparently not that of the *Crepidula* bed which overlies the leaf beds at Unga and on Popoff Island, Shumagins. However, the fauna of the latter is meager and one may not be positive as to its relations to the Controller Bay beds.

Doctor Dall submitted the following comments on the material collected in the same year from the various members of the Katalla formation:

The material is apparently all of one age and contains but one fauna, which seems to be Miocene. The bad condition of the fossils, which have been crushed and distorted, makes it impracticable to identify most of them specifically, but there are several Miocene species among them.

The prevalence of types closely recalling recent species of the same region leads to the belief that it is upper Miocene, and possibly might be even Pliocene in age, though the latter is unlikely. The rock varies from very hard tough shale to a crumbling soft sand rock, not resembling any Pliocene matrix I have seen from the coast.

Doctor Dall's report on the material collected in 1906 from the Tokun and Katalla formations is as follows:

The rocks in which these fossils are contained have been much heated, crushed, and consolidated; hence the fossils have been disturbed and broken, and, in the majority of cases, retain only impressions which, in the case of bivalves, show neither the hinge nor the muscular impressions. In many cases even the genera can only be guessed at, and the species is determinable for only one or two forms, and then except in one case, with some doubt. There is a strong probability that somewhere in the vicinity the same rocks may exist in better condition, containing recognizable fossils which, when worked out, would enable us to recognize those in worse condition, but at present this is not practicable. The fauna, so far as it can be determined, seems to be nearly or quite the same in all the localities mentioned, with the possible exception of No. 4434. Unfortunately there is very little that is characteristic in any of it. With the exception of No. 4434 the aspect is Miocene and there are two species which resemble Astoria Miocene forms very closely. No. 4434 is possibly Oligocene.

The paleontologic evidence may be summarized as follows:[a]

1. The marine Mollusca from the sandstone of the Tokun formation are either so poorly preserved as not to admit of specific identification or belong to undescribed species.[b] They are almost certainly Miocene, but can not be definitely correlated with any known Miocene faunas of other regions.

2. The plants from the coal-bearing rocks include poorly preserved individuals which suggest species of the Kenai formation of Cook Inlet, generally considered to belong in the upper Eocene or Oligocene. The best preserved specimens, however, represent species which are not known in the Kenai and which are suggestive of later Tertiary age. There is no positive evidence that the exact equivalent of the Kenai occurs in this region.

---

[a] Data furnished by W. H. Dall and Ralph Arnold on the Mollusca, F. H. Knowlton on the plants, and by W. B. Clark on the echinoids.

[b] This statement applies to all the faunas of this region.

3. The fossils of the Stillwater formation are poorly preserved, few, and not characteristic. There are no positive points of difference between this fauna and that of the Tokun formation, and it does not indicate age more closely than Tertiary.

4. The marine Mollusca from the shales of the conglomeratic beds on Kayak Island are better preserved than most of the other faunas of the region. They include among other forms a species of *Rostellites* which is considered characteristic of the Oligocene. The conglomeratic beds at the top of the Katalla formation on the mainland have not yielded characteristic fossils and are to be correlated with those on the island only on lithologic evidence.

5. The sandstones (*f*) underlying the conglomerates have yielded no fossils of positive significance in indicating age. Dall and Arnold have suggested [a] that some of these look like Eocene forms.

6. The marine Mollusca from the shales of the Katalla formation (*g* of the section on p. 37) are later than Eocene and are possibly Oligocene, though probably Miocene.

7. The marine Mollusca of the lower standstone (*h*) of the Katalla formation, as exposed on the banks of Bering River, are Miocene, and Dall suggests that they are of the same age as the fauna of the Tokun formation. The echinoids from the same beds and localities are not distinctive.

It may be seen from the preceding paragraphs that the faunas and floras are of little aid in correlating these beds with those of other regions and yield no satisfactory evidence as to the relation of these beds among themselves. There is no doubt that the entire sequence is Tertiary and post-Eocene; i. e., Oligocene or younger. The rocks of the coal field (Tokun, Kushtaka, and Stillwater formations) may with reasonable certainty be placed in the Miocene, with their base probably extending down into the Oligocene. The section south of Bering Lake presents more difficulties. If the lower beds of this section be correlated with the higher beds of the coal field the section would be all Miocene or younger. We must then conclude either that the conglomerates of the hills south of Bering Lake belong at the top of the section and are late Miocene or younger (in which case they can not be the same as the Oligocene conglomerates of Kayak Island), or that they have been placed in an abnormal position by an undetected fault, or that the determination of the Oligocene *Rostellites* is incorrect. If, on the other hand, it be assumed that the sequence in the section south of Bering Lake, as given on p. 37, is correct and that this entire section belongs below the section exposed in the coal field, then the reference of the conglomerate to the Oligocene would fit in with the reference of the rocks overlying the coal to the Miocene, and of

[a] Bull. U. S. Geol. Survey No. 250, 1905, p. 14.

the coal measures to the Miocene or Oligocene. The difficulty would then be with the lower part of the section south of the lake, and it must be assumed either that the reference of these faunas to the Miocene is incorrect and that they are Oligocene or older, or that they have been displaced by a fault of which the existence and position have been overlooked.

The stratigraphy and structure are complicated and are none too well known, but on their evidence, taking it for what it is worth, the author would be inclined to place all the rocks south of Bering Lake, with the conglomerates (correlated with those on Kayak and Wingham islands) at their top, below the section exposed in the coal field. He would then interpret the paleontology to mean that the rocks south of Bering Lake are Oligocene, that the coal measures are Oligocene with a possible transition to the Miocene, and that all the rocks above the coal are Miocene. The faunal discrepancies would then be explained as due to the insufficiency of the material at hand from these localities, and of the data for correlation with faunas representing similar geographic conditions in other localities. But if the paleontology requires it, if further study confirms the suggestion of correlations made above, then the stratigraphy and structure can and should be interpreted to meet the requirements of the paleontology. It would be strange indeed if the writer's interpretation of such structure as this should be supported in all respects by more refined methods of work.

IGNEOUS ROCKS.

Small dikes and sills are very abundant in the Tertiary rocks, especially north and east of Stillwater Creek. None were recorded between Stillwater Creek and Bering Lake, but several were seen in the region south of Bering Lake. Most of these masses are less than 1 or 2 feet thick, and none could be followed along the surface for any considerable distance. The largest and most noticeable are indicated on the geologic map (Pl. V, pocket).

Basalt is the predominant kind of rock, although three of the larger dikes were found to be of diabase. One of these, on the crest of the hill between Katalla River and Clear Creek, has a width of about 20 feet and a length of several hundred feet, and is the largest dike seen in the Tertiary rocks of the mainland.

The small basalt sills are especially interesting for the reason that they were frequently intruded along coal beds, and have altered the coal for a few inches from the contact to a dense coke with well-marked columnar joints normal to the surface of the sill.

A large mass of basaltic glass, with augite and olivine phenocrysts, was seen on the west shore of Kayak Island. It is associated with Tertiary shale and conglomerate and is probably extrusive.

Another large mass of extrusive material was seen at the north end of Kayak Island. It is of tuffaceous character, but the mineralogic composition and the stratigraphic relations were not determined.

The high southern peak of Kayak Island, known as Cape St. Elias (see Pl. IV, *B*, p. 16), and the neighboring rocky spire are seen, from the passing steamers, to be composed of a white rock, with well-developed basaltic columns, apparently of igneous character, and different from anything seen elsewhere in the region. The neighboring beaches are also composed of white pebbles which extend in gradually diminishing proportion as far as the north end of the island, where specimens were collected which proved to be dacite.

The metamorphic rocks on Wingham Island and in Ragged Mountain are associated with large numbers of igneous masses of diverse character. Most of them are much altered, in some cases to greenstone. No attempt has been made to show on the map the distribution of the various masses or to determine their microscopic character.

STRUCTURE.

The pre-Quaternary rocks of this region have a general northeast strike; have steep dips, which are northwestward throughout the

FIG. 1.—Structure on a creek in the northeast part of Bering River coal field.

greater part of the region; and are faulted. The northeast strike and northwest dip are the dominant structural features of the region. The strike varies from the northeast most markedly between Kushtaka Lake and Berg Lakes, where it is east and west, and at points in and north of the valley of Burls Creek, where it is northwest.

Monoclinal northwest dip holds throughout the greater part of the region east of Kushtaka Glacier and Kushtaka Lake. In the northeast part of this region the structure is not as simple as the uniform strike and monoclinal dip seem to indicate. The folds are in part overturned, in places complexly so, and a complicated system of overthrust faults, shown in fig. 1, adds to the complexity of the structure, which gradually increases from southwest to northeast.

The structure between Kushtaka Lake and Shepherd Creek is somewhat more simple than in the eastern district described above. In the greater part of this region the folds are open, the strike northeast, and the dip northwest, although southeast dips occur in several

areas and there is considerable variation in strike along the valley of Shepherd Creek. The structural features of this region can readily be seen by inspection of the geologic map and structure sections (Pl. V, pocket). At least four faults traverse this area. An overthrust near the crest of the southern end of Kushtaka Ridge has cut out the Kushtaka formation and brought the Tokun and Stillwater formations in contact with each other. Another fault of somewhat uncertain character extends along the western side of and about half way down Kushtaka Ridge. Along the eastern side of the valley of Shepherd Creek, from a point near the northern end of Lake Charlotte to 1½ miles below the lake, two faults bound a block of southeastward-dipping Kushtaka formation between northwestward-dipping rocks of the Tokun formation. An anticline has its axis on Carbon Creek, and another, which is probably a prong of the former, on Queen Creek. Between these a synclinal mass of the Tokun formation lies transversely across the crest of Kushtaka Ridge.

The region west of Shepherd Creek presents a variety of features. The belt of Tokun formation extending northeast and southwest from Lake Tokun contains regular structure with northeast strike and northwest dip. South of this is a syncline containing the rocks of the Kushtaka formation. This fold has an axis oblique to the general neighboring structure, is cut off on its northwest side by a fault, and has a steep northward pitch. Farther south the fault, already described as extending along the western side of Kushtaka Ridge, crosses this ridge diagonally from Shepherd Creek to Dick Creek, and along it the Stillwater formation is overthrust upon the Tokun formation. South of this fault are several folds, most of which are open. Faults probably are present, but were not detected.

The peninsula south of Bering Lake shows considerable diversity of structure. The region east of Burls Creek has north and northeast strikes, and both east and west dips. An anticline extends along the canyon of Chilkat Creek, its western flank being broken by a fault. East of this fold are several minor ones, the most noticeable being a closely compressed syncline extending diagonally across the southern end of the ridge east of Chilkat Creek, and shown on the map by the position of a belt of sandstone. It is highly probable that the western bank of the lower north and south course of Bering River is on the line of a fault.

The valley of Burls Creek and the hills northeast of it contain several folds which are revealed by the sinuous boundary of the shale and sandstone. These folds descend into the valley of Burls Creek and die out or are cut off by a fault against the steep western side of the valley.

The hills between Burls and Redwood creeks have an anticline extending northeast and southwest through the headwaters of Split

Creek. North of this is a spoon-shaped syncline, divided from the anticline by a fault. South of the anticline the monoclinal southward dip continues to the edge of the flats bordering Controller Bay. The structure of this area is shown on Pl. V (pocket). Possibly the valley of the upper east fork of Redwood Creek contains a fault which has caused a repetition of the shales and sandstones. In this case the shale in the valley of Split Creek is the same as that on the headwaters of Redwood Creek, and the sandstone on the ridge north of Redwood Creek is the same as the sandstone underlying the conglomerate on the ridge south of it. Another possibility is that the upper valley of Redwood Creek and the ridge north of it each contain a closely compressed and overturned anticline and syncline, which would cause a repetition of the beds similar to that which would occur by faulting. The shales and sandstones are near enough alike to admit of this possibility, but the fault or folds have not been found, and the presence of two shales and sandstones is indicated in other localities. These possibilities have been alluded to in the description of the Katalla formation on page 28.

The fact that the sandstones and conglomerates east of Redwood Creek are not found west of it indicates that a fault of considerable magnitude extends along the course of the creek. The hills between Redwood Creek and Katalla River have an irregular syncline on their southern end, and several small, closely compressed folds immediately west of it. An anticline lies southeast of this fold, extending southwestward from near the oil-drillers' camp at Redwood, where it is probably cut off by the Redwood Creek fault, to near the head of Katalla Slough. The northern end of the ridge west of Redwood Creek has monoclinal southeast dip.

The rocks of the crescent-shaped hill, extending from Cave Point to Point Hey, have curving strike parallel to the crest of the hill and dip toward its concave, seaward face. This appears to be the end of a seaward-pitching syncline, of which only the nose remains above the ocean. The rocks between Katalla River and the base of the steep eastern slope of Ragged Mountain have a general northeast strike and a diversity of dips which have not been interpreted.

The base of the steep mountain slope mentioned above lies on the line of contact between the Katalla formation and metamorphic rocks. The latter strike east and west, have steep and diverse dips, and are considered to be overthrust upon the younger shales of the Katalla formation.

Similar relations hold on Wingham Island, between the same metamorphic rocks and the Tertiary sandstone which is in contact with them. The sandstone and the slate here have parallel strike.

The rocks of Kayak Island strike parallel to the length of the island and have steep, often vertical, dips.

The structure of the Nichawak region has not been determined.

The structural features as described above show that these rocks have been involved in very violent crustal movements. The rocks, in spite of the apparent simplicity of structure in areas of uniform monoclinal dip, show, on closer study, that much of the simplicity is only apparent, and that extreme complexity dominates the structural features. The problems involved are illusive, and it must be admitted not only that our present knowledge of the structural details in most of the area is incomplete and unsatisfactory, but that even the broader scheme of the structure is not definitely known.

The presence of numerous faults has been alluded to above. Other faults are doubtless present, and faulting has probably played a large and important part in the development of the structure.

Certain facts concerning the presence and distribution of petroleum, which will be described later (p. 115), call for structural theories, which are not required by the distribution and attitude of the rocks at the surface. The facts difficult of explanation are (1) the presence of light-gravity petroleum, which yields on distillation a large proportion of naphthas and kerosene, in Tertiary rocks which have been highly folded, and (2) the distribution of the oil seepages in a narrow belt which is diagonal both to the structure and to belts of outcrop of rocks of different kinds.

The theory suggested in explanation of these facts will be presented in greater detail below (p. 115). This theory supposes (1) that there was, in late Tertiary or in post-Tertiary time, a zone of intense deformation in the present position of the Chugach Mountains, but that these conditions did not extend into the coastal part of the region here described; (2) that the rocks now outcropping on the shore of Controller Bay were then well to the north of their present position and were involved in these intense movements; (3) that, as a final stage in this deformation, the Tertiary rocks rode southward in one or more great overthrusts and came to rest upon Mesozoic strata, which were at a distance from the zone of intense deformation and hence not affected by it. This theory, although not directly supported by any known facts of structural detail, fits in with many facts which are otherwise unexplained. It gives significance to the straight shore of this part of the Pacific Ocean and to the clearly defined line parallel to it, which separates the high Chugach Mountains from the lower foothills. It accounts for the local absence of the Mesozoic rocks, which are so well developed (see p. 115), both north of the Chugach Mountains and in the Cook Inlet and Alaska Peninsula regions. It explains the presence of light-gravity petroleum in rocks of this age and degree of deformation, and also the distribution of the petroleum at variance with the surface stratigraphy and structure. It is not contradicted or made improbable by any known facts of the local geology.

but is supported by the fact that at the base of Mount St. Elias,[a] not far to the east and in the same position relative to the Chugach Mountains and to the Pacific shore, gneisses are known to be overthrust upon the younger and possibly upon Pliocene or Pleistocene rocks.

QUATERNARY.

MARINE SILT AND CLAY.

These deposits are best exposed on the west shore of the southeast point of Wingham Island, where they out crop in the sea cliff for one-third of a mile. They are bounded on the east by vertical conglomerate and on the west by steeply dipping sandstone. The eroded surface of the upturned edges of these Tertiary rocks have been cut or warped into a shallow trough in which the younger beds lie in a gentle syncline, with maximum dips of about 20°.

The base of these beds is below tide in the center of the trough. They extend up to a maximum of about 100 feet above high tide. The lower beds are of clay and silt, containing some sand and pebbles, with glacial scratches, and have a maximum exposed thickness of about 30 feet. Abundant, but poorly preserved, marine fossils are present. The upper beds are from 30 to 50 feet thick. They consist chiefly of coarse sand, but contain several bands, each from 6 inches to 2 feet thick, composed of gravel and bowlders with glacial scratches. They rest conformably upon the lower beds.

Similar clay, with marine fossils and scratched pebbles, were seen on the east shore of Wingham Island about 2 miles north of Kayak. They were poorly exposed at this locality. Beds of this character doubtless underlie much of the alluvial flats of the region, but, although carefully searched for, were not seen at any point except on Wingham Island. It seems probable that no other part of the region has been raised from beneath the sea in recent time.

The following report was submitted by W. H. Dall on a small collection of fossils from the west shore of the southeast point of Wingham Island:

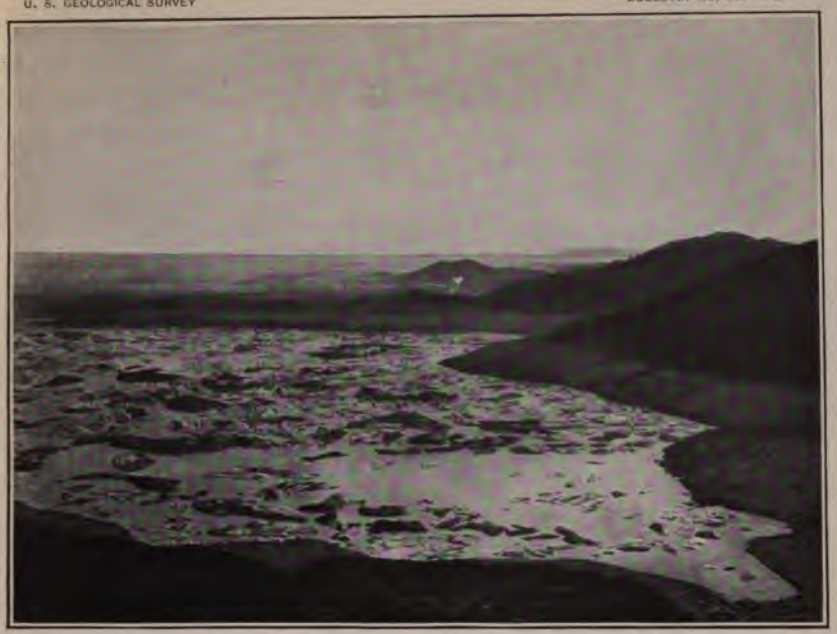
(4309) Bowlder clay fossils, much crushed and broken; contains *Serripes grönlandicus* and species of *Macoma*, *Mya* near *arenaria*, *Astarte* (?), *Tellina* (?), *Modiolus*, *Bela*, *and Balanus*, too imperfect to determine specifically.

GLACIERS.

BERING GLACIER.

Description.—Bering Glacier occupies the coastal belt between the Chugach Mountains and the ocean, from the eastern border of the

[a] Russell, Israel C., Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 35.



A. FIRST BERG LAKE WITH BERING GLACIER IN BACKGROUND, LOOKING SOUTH.

B. BERING GLACIER, SHOWING ICE CLIFFS ON THE EDGE OF BERING RIVER.

Controller Bay flats for a distance of about 70 miles eastward. Its area is probably between 1,000 and 1,500 square miles, thus closely approaching, if not equaling, in size Malaspina Glacier, the area of which was estimated by Russell to be 1,500 square miles.

This glacier, like the Malaspina Glacier not far east of it, is of the piedmont type, and as such represents the expended and coalesced termini of many valley glaciers. These tributaries originate in the high snow fields of the Chugach Mountains, flow out through all the valleys, and unite on reaching the lower levels to form a vast plateau of ice, which covers the flats from the base of the mountains to the sea. The largest of these tributaries is probably the one which heads on the divide at the source of Tana River, the largest southern tributary of the Chitina. These tributaries differ little, if any, from valley glaciers of other regions.

The most striking feature of Bering Glacier, aside from its size, is the flat surface of its main area. (See Pl. VI, *A*.) This feature, which it has in common with Malaspina and Grand Plateau glaciers, is an essential characteristic of piedmont glaciers. The tributaries come out from the high valleys on steep grades and reach the main glacier at an elevation of about 1,500 feet. From this general elevation the glacier slopes gradually toward the sea, descending both in low, even grades, characterized by a relatively smooth ice surface without wide crevasses, and in steeper slopes on which the ice is much crevassed. The western edge of the glacier is well to the west of any of the tributaries and is at a much lower level than the central part. This descent is attained chiefly by a number of steep grades, each at the end of a mountain spur, the surface of the ice being almost level between them. Good examples of such ice falls are those at the end of Carbon Mountain and at the end of the ridge east of Berg Lakes.

Moraine.—Enormous amounts of detritus are accumulated on the margin of the glacier, especially along the western and southern fronts. A large part of this moraine is on the surface of the glacier, the ice in many places being so buried as not to be visible except in the ice cliffs on the borders of lakes or in the deepest crevasses. (Pl. VI, *B*.) This surface moraine is in many places covered by dense forests which are in general restricted to a belt along the margin not more than a mile wide.

The lateral moraine, where it rests against the hills, consists usually of a ridge separated from the neighboring hillside by a water course.

Marginal lakes.—The five Berg Lakes, situated on the margin of Bering Glacier (Pl. II), near the northeast corner of the region under discussion, present some interesting features. These lakes are bordered on their landward sides by steep banks, which are in general barren of vegetation and which are covered chiefly with glacial débris.

(Pl. VI, *A*.) These banks extend to an elevation of about 1,000 feet above tide, or about 200 feet above the level of the lakes. They are cut and built into well-developed terraces, which mark former stages in the elevation of the lakes. The lower terraces are entirely barren of vegetation, but the upper ones have a scant growth of grass, herbs, and small bushes, which are only a few years old.

The surface of the four western lakes is known to be at the same altitude (about 810 feet in 1905), and Fifth Lake probably is at the same level.

These lakes are certainly connected by water channels through the crevasses of the glacier, and possibly by open spaces under the ice. The surface of the ice is level, except where it rests against the land on the points between the lakes. The identity in the altitude of the lakes, the level surface of the ice between the lakes, and the way in which bergs break off on the margin of First Lake show that this arm of the glacier is floating in one large lake, of which the five Berg Lakes are only open areas. The surface of the glacier, after a gentle slope, descends in a low, crevassed icefall to its floating level.

The level of the lake is oscillating. The absence of vegetation on the lower terraces shows that it has fallen in recent years. In June, 1905, it was rising several inches per day. The outlet of the lake, which is beneath the ice at the end of the long point south of First Lake, becomes choked with débris at irregular intervals. The water then rises until the pressure clears the outlet or till the water can flow on the surface around the end of the point, when the lake is emptied, causing severe floods in the valley of Bering River.

Conditions are similar to those at the Märjelen See,[a] except that at Berg Lakes a large area of glacier is floating in one large lake, which appears on the surface as five small ones. Lake Cætani, Mirror Lake, and the numerous other marginal lakes[b] at the head of Yahtse River, between the edge of Malaspina Glacier and the sides of Chaix Hills, possibly offer a closer resemblance, though Russell has not stated whether any of these lakes are at the same level and possibly connected. Most of them, however, are described as not at the same level.

A series of chains of small marginal lakes, of somewhat different type, extends along the western margin of the glacier between Bering River and Nichawak Mountain. These lakes are bordered on one side by the margin of the ice and on the other by the terminal moraine.

MARTIN RIVER GLACIER.

Description.—This glacier, which is situated between the hills north of Bering River (Pls. I, p. 10; IV, *A*, p. 16) and the base of the

[a] Lyell, Sir Charles, Principals of geology, 10th ed., 1867, vol. 1, pp. 376–379.

[b] Russell, Israel C., Second expedition to Mount St. Elias, 1891; Thirteenth Ann. *Rept. U. S. Geol. Survey*, pt. 2, 1893, pp. 76–80.

Chugach Mountains, has an area of about 100 square miles, not counting its uttermost tributaries, some of which extend for an unknown distance into the mountains. It resembles Bering Glacier, in being situated at the base of the Chugach Mountains, in having its longest dimension parallel to the mountains, and in being the united dissipator of many smaller glaciers, which descend from the high mountains.

It differs from the Bering and Malaspina glaciers in having a range of hills along its southern margin. It is consequently, in shape and position, somewhat like a large valley glacier, although it differs from valley glaciers of the usual type, and resembles piedmont glaciers, in being a nearly stagnant mass of ice along the front of the mountains which supply the reservoirs of its tributaries, and in having those tributaries on only one side. But for the nonessential position of the hills of the Bering River coal field between it and the coast, it would be a piedmont glacier. It may, perhaps, best be placed in an intermediate class.

The tributaries come out from the mountains on steep grades, joining others, swelling their volumes at almost every valley they pass. From each of these points of juncture, below snow line, a band of medial moraine is formed from the lateral moraines of the uniting glaciers (Pl. IV, *A*, p. 16). The formation of the main glacier takes place in the same way as its immediate tributaries, and long lines of medial moraine extend down from each juncture point. These moraines spread out and become scattered over the broad surface of the flat expansion of the lower end of the main glacier. The condition of much of this surface is not unlike that of the Bering Glacier, being flat, not much crevassed, covered with a heavy coating of moraine, and having forests over a considerable part of it. Descending lobes extend into the valleys of Kushtaka Lake and Lake Charlotte.

Moraine.—The lateral moraine on the southern margin of the glacier consists of heavy accumulations of débris, separated from the bordering hillsides by watercourses, between which and the general surface of the glacier the moraine forms a high sharp ridge.

The terminal moraine across the western end is a broad, hummocky mass of detritus, which grades imperceptibly, as far as the surface is concerned, into the moraine-buried and forested end of the glacier.

Marginal lakes.—There are two small marginal lakes on the northern edge of the glacier. Like Berg Lakes, each of them is imprisoned between a mountain spur and the edge of the ice.

MINOR GLACIERS.

Slope Glacier, three small glaciers near it, and an unknown number of small glaciers on the west side of Ragged Mountain (only one of which is shown on the map) are of interest in showing the favorable conditions for the formation of glaciers which now exist in this

(Pl. VI, *A*.) These banks extend to an elevation of about 1,000 feet above tide, or about 200 feet above the level of the lakes. They are cut and built into well-developed terraces, which mark former stages in the elevation of the lakes. The lower terraces are entirely barren of vegetation, but the upper ones have a scant growth of grass, herbs, and small bushes, which are only a few years old.

The surface of the four western lakes is known to be at the same altitude (about 810 feet in 1905), and Fifth Lake probably is at the same level.

These lakes are certainly connected by water channels through the crevasses of the glacier, and possibly by open spaces under the ice. The surface of the ice is level, except where it rests against the land on the points between the lakes. The identity in the altitude of the lakes, the level surface of the ice between the lakes, and the way in which bergs break off on the margin of First Lake show that this arm of the glacier is floating in one large lake, of which the five Berg Lakes are only open areas. The surface of the glacier, after a gentle slope, descends in a low, crevassed icefall to its floating level.

The level of the lake is oscillating. The absence of vegetation on the lower terraces shows that it has fallen in recent years. In June, 1905, it was rising several inches per day. The outlet of the lake, which is beneath the ice at the end of the long point south of First Lake, becomes choked with débris at irregular intervals. The water then rises until the pressure clears the outlet or till the water can flow on the surface around the end of the point, when the lake is emptied, causing severe floods in the valley of Bering River.

Conditions are similar to those at the Märjelen See,[a] except that at Berg Lakes a large area of glacier is floating in one large lake, which appears on the surface as five small ones. Lake Cætani, Mirror Lake, and the numerous other marginal lakes[b] at the head of Yahtse River, between the edge of Malaspina Glacier and the sides of Chaix Hills, possibly offer a closer resemblance, though Russell has not stated whether any of these lakes are at the same level and possibly connected. Most of them, however, are described as not at the same level.

A series of chains of small marginal lakes, of somewhat different type, extends along the western margin of the glacier between Bering River and Nichawak Mountain. These lakes are bordered on one side by the margin of the ice and on the other by the terminal moraine.

MARTIN RIVER GLACIER.

Description.—This glacier, which is situated between the hills north of Bering River (Pls. I, p. 10; IV, *A*, p. 16) and the base of the

[a] Lyell, Sir Charles, Principals of geology, 10th ed., 1867, vol. 1, pp. 376–379.

[b] Russell, Israel C., Second expedition to Mount St. Elias, 1891; Thirteenth Ann. *Rept. U. S. Geol.* Survey, pt. 2, 1893, pp. 76–80.

Chugach Mountains, has an area of about 100 square miles, not counting its uttermost tributaries, some of which extend for an unknown distance into the mountains. It resembles Bering Glacier, in being situated at the base of the Chugach Mountains, in having its longest dimension parallel to the mountains, and in being the united dissipator of many smaller glaciers, which descend from the high mountains.

It differs from the Bering and Malaspina glaciers in having a range of hills along its southern margin. It is consequently, in shape and position, somewhat like a large valley glacier, although it differs from valley glaciers of the usual type, and resembles piedmont glaciers, in being a nearly stagnant mass of ice along the front of the mountains which supply the reservoirs of its tributaries, and in having those tributaries on only one side. But for the nonessential position of the hills of the Bering River coal field between it and the coast, it would be a piedmont glacier. It may, perhaps, best be placed in an intermediate class.

The tributaries come out from the mountains on steep grades, joining others, swelling their volumes at almost every valley they pass. From each of these points of juncture, below snow line, a band of medial moraine is formed from the lateral moraines of the uniting glaciers (Pl. IV, *A*, p. 16). The formation of the main glacier takes place in the same way as its immediate tributaries, and long lines of medial moraine extend down from each juncture point. These moraines spread out and become scattered over the broad surface of the flat expansion of the lower end of the main glacier. The condition of much of this surface is not unlike that of the Bering Glacier, being flat, not much crevassed, covered with a heavy coating of moraine, and having forests over a considerable part of it. Descending lobes extend into the valleys of Kushtaka Lake and Lake Charlotte.

Moraine.—The lateral moraine on the southern margin of the glacier consists of heavy accumulations of débris, separated from the bordering hillsides by watercourses, between which and the general surface of the glacier the moraine forms a high sharp ridge.

The terminal moraine across the western end is a broad, hummocky mass of detritus, which grades imperceptibly, as far as the surface is concerned, into the moraine-buried and forested end of the glacier.

Marginal lakes.—There are two small marginal lakes on the northern edge of the glacier. Like Berg Lakes, each of them is imprisoned between a mountain spur and the edge of the ice.

MINOR GLACIERS.

Slope Glacier, three small glaciers near it, and an unknown number of small glaciers on the west side of Ragged Mountain (only one of which is shown on the map) are of interest in showing the favorable conditions for the formation of glaciers which now exist in this

region, and in showing what the probable conditions were during the maximum local extension of the ice.

These glaciers come from snowfields, which in some cases do not extend above an elevation of 2,700 or 2,800 feet, and in general melt away at elevations of from 2,000 to 2,500 feet. They thus establish the fact that the present local snowline is below 2,700 feet, and this is confirmed by the medial moraines on the larger glaciers, which appear at an elevation slightly less than 2,500 feet.

GLACIAL DEPOSITS.

MORAINE.

The maximum known glaciation of this region is represented by the moraine shown on the geologic map (Pl. V, pocket) as bordering Martin River Glacier, and by numerous small cirques which are quite generally distributed over the higher ridges.

The old moraine of Martin River Glacier extends for a varying distance up the northwest slope of Cunningham Ridge, descends into the valley of Stillwater Creek, encircles Kushtaka Lake, rides over the sides and northern end of the group of mountains between Kushtaka Lake and Lake Charlotte, and borders the northern flank of the group of hills west of Lake Charlotte. The position of this moraine on low ground is on the line of little hills at the southwest end of Kushtaka Lake, one-half mile below the outlet of Lake Charlotte in the Shepherd Creek valley, and about three miles beyond the present front of the glacier in the Martin River valley. It extends up the hillside to maximum elevations of 600 or 700 feet above the present position of the edge of the glacier. The corresponding moraine of Bering Glacier has not been mapped, but foreign morainic material is known to be absent from the valleys bordering on Berg Lakes at elevations exceeding about 1,000 feet, or about 200 feet above the present vertical position of the glacier, and also from the north banks of Bering River on both sides of Stillwater Creek at distances of one-half mile and one-third mile from the present margin of the ice.

These facts indicate that conditions of maximum glaciation were represented by an increase in the extent of Martin River Glacier to the limits indicated above, by little if any extension of Bering Glacier (at least along its northwest margin), and by the presence of a large number of small glaciers in sheltered valleys. The vertical position of the latter, compared with the present distribution of such glaciers in this region, shows that the snow line was then about 1,000 feet lower than it now is. This might mean, as far as the evidence from existing glaciers and abandoned cirques is concerned, that either general climatic changes, or a change of 1,000 feet in the elevation of the land, caused the change of 1,000 feet in snow line. Other lines of *evidence*, such as the depth of alluvium-filled valleys, indicate that

change in level has been responsible for the rise in the snow line and the retreat of the glaciers.

The restriction of morainic material to the limits indicated above might be explained according to the following hypotheses:

1. That moraine formerly existing has been removed by erosion.

2. That the region was submerged during maximum glaciation to such an extent that the glaciers entered the sea at the present lower limits of the moraine.

3. That extreme glacial conditions were so mild as not to send the ice beyond the present known extent of the moraine.

4. That the land was elevated during the maximum glaciation, and that the large glaciers went out through valleys now submerged or filled with alluvium.

The first hypothesis fails in that the complete removing of all material (even in sheltered places) over most of the area is unexplained and most improbable, especially in the presence of the large, untouched moraines bordering the present position of Martin River Glacier and of many small, untouched moraines composed of local material in other places. We have to deal with the presence of large moraines composed of foreign material at the lower altitudes and near the Martin River Glacier, and of small moraines composed of local material at high altitudes and in localities sheltered from melting, and with the absence of all moraine at intermediate altitudes. The distribution calls for an explanation of genetic origin. Destructional agencies could not be so complexly selective in the distribution of their fields of operation.

The second hypothesis fails by the absence of any physiographic or sedimentary evidence of such submergence. There are no wave-cut benches; no elevated beaches, except the lake beaches described on p. 52; and no unconsolidated marine sediments, except those occurring at a low level on Wingham Island. (See p. 46.)

The third hypothesis can be accepted as far as it refers to the upward limit of the moraine of the larger glaciers and to the extreme limits of the small, local, cirque-bound glaciers. The possibility of further extension of the large glaciers beneath the present alluvium must, however, be admitted. This will be considered under the fourth hypothesis, which is more comprehensive than the third.

The fourth hypothesis is harmonious with all the evidence at hand. If the land were elevated 1,000 feet the snow line would fall the same distance and local glaciers would form in the now abandoned glacial cirques. The lowering of the snow line would increase the reservoir area of the larger glaciers, and hence their flow. They would rise on the hillsides, presumably to some such elevation as that of the high moraines bordering Martin River Glacier. They would extend their valley tongues, but this extension would be buried by river deposits

during subsequent depression. The broad alluvial flats are known to be filled with unconsolidated material to depths exceeding 280 feet in Katalla Valley and exceeding 580 feet on the east bank of Bering River, the total depth in both cases (pp. 119, 121) being unknown. The glaciers, during such an elevation, could consequently have extended far beyond the present ocean shore. In this connection there is significance in Dawson's suggestion[a] that the bowlder clay described by him from Middleton Island was laid down in the sea during a hypothetical extension of Pleistocene glaciers from the mainland. Middleton Island is 76 miles southwest of Katalla and 50 miles from the nearest shores of Montague and Hinchinbrook islands. It lies inside the 100-fathom curve, as given on the present charts, and hence would probably be connected with the mainland during any such elevation as is supposed above.

LAKE DEPOSITS.

The five Berg Lakes on the margin of Bering Glacier, the physiographic features of which have been already described (p. 47), are bordered on their landward sides by banks which, up to an elevation of about 200 feet above the level of the lakes, are cut and built into terraces which mark stages in the former elevation of the lakes. These terraces are composed of glacial débris which has been reworked by the waters of the lakes. These deposits are known to be very thin in places, where ledges of rocks are exposed, but their maximum thickness is not known.

STREAM AND BEACH DEPOSITS.

The eastern shore of Bering River, and of Controller Bay, from the margin of Bering Glacier to the ocean, is a flat plain of mud, sand, and gravel, constantly growing by the addition of sediment which the glacial streams carry and deposit along their courses and at their mouths. Nichawak Mountain, Mount Campbell, Gandil Mountain, and the Suckling Hills rise like islands from this plain, and it seems certain that a very short time ago they were islands in an older extension of Controller Bay, which was then, as now, being filled by the sediment of these glacial streams. These younger fluviatile Quaternary deposits cover large areas in the valleys of Canyon and Stillwater creeks, and extend along the northern bank of Bering River from Shockum Mountains to Bering Lake. They also extend up the valley of Shepherd Creek to one-half mile below Lake Charlotte and to the moraine across the southwest end of Lake Kushtaka. The valley of Katalla River and of the streams which head near it and flow into Bering Lake is floored with the same material, as are also

[a] *Dawson*, George M., Notes on the Geology of Middleton Island, Alaska: Bull. Geol. *Soc. Am.*, vol. 4, 1892, pp. 427–431.

the lower courses of most other streams which enter Controller Bay. These unconsolidated deposits, an unknown amount of which are of fluviatile origin, are known to have a thickness of over 580 feet at one point on Bering River, and of over 280 feet in the Katalla Valley.

The beaches, bars, and islands, which the ocean waves are building along these shores, are composed largely of reworked fluviatile and glacial material, and are in part contemporaneous with the stream deposits. Good examples of these are: Okalee Spit, all of Kanak Island, the beach from Strawberry Point to Katalla, Softuk Bar, and the long line of islands which extend in line with the last named across the entire front of the Copper Delta.

Not only are these deposits building now but they have formed in the past, and some of the older ones are still in existence. The beach from Cave Point to Katalla is a broad, gently curving stretch of sand, concave toward the ocean. Its dry crest is covered with a narrow but dense growth of spruces. Behind it is Katalla Slough, a muddy, winding channel whose general course is parallel to the beach. Another line of spruces, parallel to the outer beach, is situated behind the slough. These spruces grow in beach sand, and behind them is another swamp area containing a winding slough. A view from one of the neighboring hills reveals the fact that Katalla Valley, for a distance of several miles inland, is made up of alternating sandy strips and muddy areas; each of the former with a line of spruces, each of the latter with a winding slough or a line of small ponds. The sandy strips are former beaches, which grew as the outer beach at Katalla has grown, across the valley from a rocky foreland. The trees are older as one goes inland, and their age (if the oldest of each beach were still there) would tell us the age of the beaches. The sloughs are more poorly preserved at a distance from the coast, and the distribution of trees is less regular. This means that sediment from the river and wash from the smaller streams are filling the sloughs and spreading gravel and sand on the mud of their banks. The original trees are dead and their descendants have spread out a bit where only grass grew at first. Farther inland the sloughs are filled and the stream wash has buried the beaches. Perhaps even there a line of trees may mark one of these old skirmish lines which the land threw out in its fight with the ocean.

DESCRIPTION OF LAND FORMS.

ADJACENT REGIONS.

The southern coast of Alaska from the shores of British Columbia to the Alaska Peninsula lies on an arc, concave toward the ocean, having a radius of about 500 miles and with its center at approximately longitude 146° W., latitude 53° N. The contour of the ocean bottom, the larger aspect of the trend of shore line, the coastal mountains,

and range after range of interior mountains all lie approximately parallel to this arc.

The coastward front of the Pacific Mountain system includes the Kenai Mountains on the Kenai Peninsula and the west shore of Prince William Sound, the Chugach Mountains on the north shore of Prince William Sound and in the vicinity of Copper River, and the Fairweather Mountains from near Mount St. Elias to Cross Sound. These mountains rise, for the most part, sharply from the sea. They are not cut through by tidal waterways between Cook Inlet and Cross Sound, though deeply embayed at Prince William Sound and Yakutat Bay. West of Copper River and east of Icy Point the coast is fiorded, but this condition does not hold between these points except at Yakutat and Lituya bays. The coastal mountains are not cut through by river courses between the Copper and the Alsek. It is significant that east and west of these two rivers the mountains approach closely to the sea and the coast is fiorded. Between these rivers the mountains lie farther inland and the fiords are absent (except at Yakutat Bay). In this interval the region between the mountains and the sea includes mountains of less relief than the main range, and is made up of rocks which are younger, in general less closely folded, and always less indurated and altered.

The high mountains from Copper River to Cross Sound are the gathering ground for the greatest system of low-altitude, low-latitude glaciers in the world. These glaciers pour out toward the sea from every gap and pass between Copper River and Cross Sound. They have overflooded the coastal hills and lowlands and have formed a series of broad, flat-topped, stagnant, piedmont glaciers, of which the Malaspina has long been regarded as a unique type, but which has companions rivaling it in size in Grand Plateau Glacier to the east and Bering Glacier to the west.

At the western extremity of the coastal lowlands described above, and just east of Copper River, is Kayak Island. West of Kayak Island is Wingham Island, and north of them is Controller Bay.

SHORE LINE.

Kayak Island almost joins the mainland at its north end, from which it extends as a narrow rocky mass for 20 miles out to sea. Cape Suckling is a rocky promontory on the mainland about 12 miles east of the northern end of Kayak Island. West of it the shore curves slightly northward for about 4 miles, to where Okalee Spit, a low strip of sand about 9 miles long and from 500 to 3,000 feet wide, reaches westward, dividing the waters of Controller Bay from those of the ocean. The spit is the product of the waves working on débris from the seaward face of Bering Glacier, and its direction is that of the prevailing winds.

A. LOWER END OF BERING RIVER CANYON.

B. HEADWATERS OF BERING RIVER AT THE UPPER END OF THE CANYON AT THE SOUTH END OF CARBON MOUNTAIN.

Behind Okalee Spit the east shore of Controller Bay extends northwest to the mouth of Bering River. In this interval it is broken by the mouths of many rivers, which are pouring out with their water vast quantities of mud and sand. This sediment is derived from the southwest side of Bering Glacier, and is fast extending the low shores between which it flows and reducing both the area and the depth of the bay. The north shore of Controller Bay, between Bering River and Point Hey, is likewise bordered by muddy flats. Kanak Island, which lies across the west side of the bay, opposite the mouth of Bering River, is composed of similar material.

Katalla Bay, between Strawberry Point and Whale Island, is bordered by a gently curving beach, which is the outermost and youngest of a series of beaches (see p. 53) by which the land has here advanced, reclaiming the present Katalla Valley from the sea.

Softuk Bar, 2 miles northwest of Whale Island, is a long, narrow spit which is similar to Okalee Spit in size, shape, position, and direction. It is situated at the eastern end of a long line of low, sandy islands which extend across the entire front of the Copper Delta.

DRAINAGE.

RIVERS.

The streams of the Controller Bay region have their supply in part from local rainfall and in part from the glaciers which have invaded the region and which melt away on its borders. The supply from both sources is large. The rainfall, as was shown above (pp. 17–19), probably exceeds 150 inches a year, while the glaciers contribute the precipitation of many hundred square miles. The streams are consequently large in proportion to their length and drainage area, and are all subject to severe floods.

The greater part of the region lies in the valley of Bering River. This stream has its source on the margin of Bering Glacier (Pl. VII, *B*) in the northeast part of the area covered by the map. It flows southwest for about 12 miles until it approaches Bering Lake, where it spreads into a broad delta. Part of the water passes directly through the southeast corner of the delta without entering the lake. The other part enters the lake through many channels along its eastern margin, then turns directly back along the south shore of the lake and joins the streams which cut past the lake without entering it. The reunited waters then flow south for about 8 miles and enter the northeast corner of Controller Bay. The lower course of Bering River is tidal, the water of Bering Lake rising and falling from 1 to 3 feet, and the currents running in and out at from 3 to 5 miles per hour. Above Bering Lake the river is nontidal and has a strong current of from 3 miles per hour in the vicinity of the delta to 6 to 10 miles per hour in the upper part.

The tributaries of Bering River above the lake include Canyon Creek, which has its source on the southern margin of Martin River Glacier; Stillwater Creek, which drains Lake Kushtaka and receives a large part of its supply from the Kushtaka Glacier; and Shepherd Creek, which drains Lake Charlotte and several other small lakes on the margin of the Martin River Glacier. The chief tributaries below the lake are Gandil and Nichawak rivers, which drain parts of the margin of Bering Glacier.

The other streams include Campbell and Edwardes rivers, which rise on the southwest margin of Bering Glacier and enter the east shore of Controller Bay; Katalla River which rises in the hills west of Bering Lake and flows into Katalla Bay, and several of the headwater tributaries of Martin River. The latter rises on the western margin of Martin River Glacier and in Tokun Lake, and flows west until it reaches the eastern edge of the Copper Delta. The waters divide here, part entering Copper River, and part flowing along the edge of the mountains close to the delta and entering the tidal sloughs behind Softuk Bar.

LAKES.

Bering Lake is a former arm of Controller Bay which has been cut off from the bay by the growth of the deltas of Bering River and its lower tributaries.

Charlotte and Kushtaka lakes have dams, composed of the terminal moraine of a former glacial expansion, across their southern ends. The former drains out through a breach in the dam, the latter at a point near the other end of the lake, either over a sapped col or over a lateral wall of moraine.

Lake Tokun was formed as a marginal lake on the former expansion of the Martin River Glacier. The lateral moraine deposited across the end of the lake during this expansion still holds the waters of the lake.

A series of lakes along the southern side of Martin River are of considerable interest, because they are still in process of formation. Martin River is a heavily loaded stream and is building flood plains along its course. It is carrying and depositing more sediment than its nonglacial tributaries and is building up its flood plain across the mouths of these tributaries. The result is to pond each clear-water tributary and to form a lake in the lower part of its valley. The present growth of these lakes is shown both by the continuation of the processes which caused them and by the fact that they have no beaches and that the forests on their margins are being submerged and killed by the rising waters. A similar lake is now in the initial stage of formation at the mouth of Shepherd Creek. Other lakes intimately associated with the glaciers are discussed on pages 47, 49

RELIEF.

DISTRIBUTION OF THE HILLS.

The shores of Controller Bay include broad areas of marshes in which are island-like masses of hills, many of which have a northeast-southwest trend like Kayak Island. Together they constitute a group with the same general trend, which rises gradually toward the northeast until it merges with the higher mountains farther inland. These hills thus constitute a spur which, extending southwest from the high mountains far toward the continental shelf, has turned aside the glaciers coming from the mountains, so that its landward parts, with the recesses between its members, are bare of ice, though on the very edge of the Bering Glacier. Its seaward parts give some protection from the ocean and make a slight break in the strip of unprotected coast which in general marks the glacier-covered lands east of it.

The Chugach Mountains, although they have the appearance of a range with an east and west axis and are bordered both on the north and south by straight east and west lines, and composed, locally at least, of minor ranges which extend in a northeast-southwest direction. This feature is well shown on the reconnaissance map (Pl. I) and in Pl. IV, *A* (p. 16). Some of the smaller ranges in the vicinity of Mount St. Elias (see Pl. I) have a similar trend.

The region is about half hilly and half lowland. The lowlands are flat and swampy and rise but a few feet above tide. The hills are in general less than 2,000 feet high, but reach a maximum of about 4,000 feet in the northeast corner of the region. They include a range extending throughout the region from northeast to southwest and several detached areas; two of the latter are in the ocean and form Kayak and Wingham islands. The others, including the Suckling Hills, the four detached masses of hills in the Nichawak region, and the peninsula south of Bering Lake, rise like islands out of the swampy flats.

ACCORDANCE OF ELEVATIONS.

CREST LINES.

The crests and summits of the ridges in various parts of this region possess much diversity in altitude, yet close observation shows that the elevations are grouped within certain bounds, that there are more or less definite heights to which certain groups of hills rise, and that between these elevations steep slopes are found, but seldom hilltops and almost never groups of hilltops or ridges with anything like uniform altitudes.

The general or average elevations of the ridges or groups of hills which possess such uniformity are shown in the following table:

General levels of ridge crests.

Position.	Elevations in feet.									
Carbon Mountain	3,500	.....	2,450	.....	1,800					
Between Canyon Creek and Kushtaka Lake	.....	.....	2,450	2,100	1,800					
Charlotte and Kushtaka ridges	.....	.....	2,450							
Shockum Mountains	.....	.....	.....	.....	.....	1,500	.....	.....	800	
Ridge west of Shepherd Creek	.....	.....	2,450	2,100	1,800					
Hills west of Bering Lake	.....	.....	.....	2,100	.....	.....	.....	.....	800	
Hills south of Bering Lake	.....	.....	.....	2,100	1,800	1,500				
Ragged Mountains	.....	3,000	2,450	2,100	.....	.....	1,250			
Gandil Mountain	.....	.....	.....	.....	.....	.....	.....	.....	800	
Nichawak Mountain	.....	.....	.....	.....	.....	.....	1,250	1,000		
Mount Campbell	.....	.....	.....	.....	.....	.....	1,250			
Suckling Hills	.....	.....	.....	.....	.....	.....	1,250	.....	800	
Kayak Island	.....	.....	.....	.....	1,800	.....	1,250	.....	.....	600

The highest summits in this region are on the northern end of Carbon Mountain, in the extreme northeast end of the area covered by the map, where a small group of peaks attains altitudes of from 3,800 to 4,150 feet, and large adjacent areas (not shown on the map) are even higher. The crest of Carbon Mountain from this group of peaks westward along the southern margin of Slope Glacier holds a general uniform altitude with the summits ranging from 3,450 feet to 3,600 feet, averaging 3,550 feet; the cols from 3,300 feet to 3,500 feet, averaging 3,450 feet; and the general crest line averaging 3,500 feet. The ridge then drops sharply to a lower level almost 2,000 feet below.

Nothing like this higher level is attained elsewhere in the region, although a few peaks on Ragged Mountain have elevations of about 3,300 feet, and similar elevations may be found in some of the peaks along the southern flank of the Chugach Mountains.

The next lower general level is slightly above 3,000 feet and is seen in the serrated top of Ragged Mountain, which holds this general elevation for about 6 miles of linear crest until it approaches, at the south end, within 3 miles of the sea. It then drops sharply in three steps to general elevations of about 2,450 feet, 2,100 feet, and 1,200 feet.

The 2,400-foot level may be seen in the central part of the ridge west of Shepherd Creek, in the higher crests and summits of Charlotte and Carbon ridges, and possibly in Cunningham Ridge (although in the latter case two peaks, Monument Mountain and Mount Chezum, reach elevations of 2,650 and 2,850 feet, respectively), and in some of the lower spurs of Carbon Mountain.

A very distinct level at about 2,100 feet is represented in the northern end of the ridge between Clear and Canyon creeks, in the ridge west of Shepherd Creek (except north of the Tokun-Charlotte pass and in the central group of high peaks discussed above), in the

high ridge west of Bering Lake, on the higher ridges south of Bering Lake, on parts of Ragged Mountains, and in many of the lower spurs and ridges along the southern front of the Chugach Mountains (see Pl. IV, *A*, p. 16). This is, in its wide distribution and in the usual perfection of its development, perhaps the most striking level of accordant summits in the entire region.

A 1,700 to 1,800-foot level is reached by many of the peaks on the southern end of Carbon Mountain, by the southern end of the ridge west of Canyon Creek, by the ridges between lakes Charlotte and Tokun, and by the ridge east of Katalla River.

Lower levels at 1,200 feet, at 800 feet, and at 500 feet are held by many of the lower ridges, especially those near the coast.

TERRACES AND BENCHES.

The hillsides in all parts of the region have been cut into benches and terraces, some being broad and flat, and others being narrow shelves, small flat areas on the spurs of the hills, or locally widened or gently graded places along the streams. The better developed of these features can be followed at a constant level for considerable distances along the hillsides, but some are of local extent and perhaps give way to others at somewhat greater or less elevation. The altitudes of the benches in the several valleys are shown in the following table:

Elevations of terraces and benches.

Position.	Elevations in feet.						
Bering Lakes	2,000	1,750	1,450				
Canyon Creek		1,700	1,450	1,250	1,000	750	
Clear Creek		1,700	1,450	1,250	1,000		
Trout Creek					1,000		
Shockum Mountains				1,200			500
East side of Kushtaka Ridge				1,200	1,000		
Shepherd Creek, east side		1,600			1,050	800	
Shepherd Creek, west side			1,450	1,250	1,000	750	
Lake Tokun					950		
Dick Creek				1,200	950	750	
Bering Lake, south shore				1,250	1,000	750	500
Bering River, below lake				1,250			500
Chilkat Creek				1,250	1,000		
Burls Creek					1,000		500
Puffy Creek					1,000		
Redwood Creek					1,000		600
Katalla Valley, east side					1,000	750	
Katalla Valley, west side				1,250		750	
West of Ragged Mountain						750	

Many of the divides are broad and flat and have lakes and meandering drainage upon them, this condition being well illustrated between Dick Creek and Lake Tokun and between Lake Tokun and Lake Charlotte. The divides there stand at very distinct terrace levels. Besides existing lakes, the Dick Creek-Tokun Lake divide possesses the further interesting feature of a drained lake bed with the beaches and lacustrine silts which were formed while the lake was there. The drainage of the lake was probably caused by piracy of the creeks tributary to Tokun Lake.

SIGNIFICANCE OF CREST AND BENCH LEVELS.

It may be seen that these elevations accord approximately with those of some of the ridges. The levels of the benches, like those of the ridges, are in part independent of the character and attitude of the rock. They are, consequently, to be interpreted as due to past erosional conditions, which were determined by different positions of base-level from those existing now. They show that, subsequent to the indurating and folding of the rocks, erosion progressed so far that topographic conditions approached or attained those of a peneplain. It can not be assumed, however, that each of these levels represents a peneplain, nor can it be assumed that any definite level represents one. The number of the approximate levels shows that the history of denudation has been complex, but the age of the rocks shows that the length of time in which it was accomplished was very short, and it may well be that at no time has the topographic relief approached closely to maturity. Repeated cuttings of straths and coastal benches, after each of which the land rose a little, might easily produce such features as now exist. On the other hand, it may be that the higher levels were produced by complete peneplanation, while the lower ones each represent a less complete reduction after a renewal of uplift; or that one of the intermediate levels represents a dissected peneplain, with the higher elevations as unreduced residuals. However this may be, it is certain that the region has been nearer to a condition of topographic maturity in the past than it is now.

The present land forms were produced by the uplift and erosion of those older surfaces without known warping. The older surfaces extend over and through this region in levels or in steps, and not in curves. The surfaces extend northward until they run into the southern front of the Chugach Mountains. This shows that they are younger than the high mountains, unless a recent fault or very abrupt flexure marks the very edge of the range. The latter possibility is contradicted by the fact that there is little accordance of summits and that no flat areas appear on the crest of this part of the Chugach Mountains. The foothills have, consequently, a history somewhat different from the high range, and have been reduced to levels which did not cut far back from shore.

VALLEYS.

The presence of the broad alluvium-filled valleys which extend throughout most of the region is one of its most striking physiographic features. These valleys are very broad in proportion to the size of the streams occupying them, and suggest at once that they are deeply filled and were produced when the land stood much higher *than now*. This is confirmed by the fact that a drill hole on the

east shore of Bering River opposite the lower island and another on Katalla River went to depths of 580 feet and 280 feet, respectively, without reaching bed rock. Further evidence concerning the former position of the snow line (p. 50) suggests that the valleys were cut when the land stood about 1,000 feet higher than at present. In this case the rock floor in the centers of the valleys and at their lower ends should be almost 1,000 feet below sea level.

Many of the smaller streams have their headwater courses down to about 1,000 feet above sea level in glacial cirques. The problem which these present will be discussed later. The lower courses of these streams from an elevation of about 1,000 feet down to the edge of the alluvial flats are usually in box canyons. The descent from the cirques or terraces into the lower canyons is usually in one or more waterfalls.

HISTORICAL GEOLOGY.

The earliest geological event of which there is a definite record in this region was the deposition of the material which now constitutes the slate, graywacke, and associated rocks on Wingham Island and Ragged Mountain. This material was derived from the destruction of other rocks of unknown character. The date of deposition is also somewhat uncertain, but the weight of evidence indicates (see p. 27) that it was toward the end of the Paleozoic era. These rocks were deposited in the sea, for they contain marine fossils. The fineness of much of the material shows that the shore was at times distant. The presence of volcanic material, some of which is probably interbedded with the other rocks, indicates that land may have been near at other times, and that there were volcanic vents, either continental, insular, or submarine, which probably were not far away.

These deposits were elevated, consolidated, folded, and metamorphosed at a date or dates concerning which there is little evidence. Similar and probably contemporaneous rocks in other regions in this part of Alaska are known to have been folded and metamorphosed prior to Upper Triassic time. Igneous material has been introduced into these rocks, but there is no evidence as to the date of the intrusion. It may have been soon after the deposition or not until long after the main folding.

No record of the Mesozoic, unless it be in the slaty rocks referred to above, has been preserved in this region. The evidence from other provinces, barring the possibility [a] of the slaty rocks on the coast from Yakutat to Kodiak being Mesozoic, indicates that much of the area of the Chugach Mountains and probably of their extension through the southern part of Kenai Peninsula and through Afognak and Kodiak Islands may have been land during Mesozoic time. Triassic seas

[a] See discussion of the age of these rocks on p. 27.

extended through part of the region north of Chitina River and in the Cook Inlet and Alaska Peninsula region. A period of folding and probably of mountain building came at or somewhat after the close of Triassic time. Deposition was apparently somewhat restricted during the Lower Jurassic, for sediments of that age are known only from Cook Inlet and the Alaska Peninsula. The sea probably covered larger areas in the Middle Jurassic, when deposits were laid down in the present position of the Alaska Range, the Matanuska Valley, Cook Inlet, and the Alaska Peninsula. Upper Jurassic seas widened still more, for deposits of that age are known throughout much of southeastern Alaska, the valleys of Copper and Matanuska rivers, Cook Inlet, the Alaska Peninsula, and the Yukon Valley.[a] The post-Triassic unconformity and period of folding may have lasted until the beginning of Upper Jurassic time, for the evidence of the unconformity is seen in the relation of Upper Jurassic to Upper Triassic rocks.

The great Mesozoic granitic intrusions, which began after the close of the Triassic, were probably over in at least part of Alaska before the beginning of the Upper Jurassic, though they extend in other districts into the Cretaceous. In the Cook Inlet region the granitic intrusions do not cut rocks younger than the Triassic, the Jurassic intrusions and flows being of andesite, and the Tertiary and post-Tertiary intrusion of andesite and basalt. Lower Cretaceous sedimentation took place in widely scattered provinces and apparently over broader areas, especially in the northern part of Alaska, than were covered by the Middle and Upper Jurassic seas. The Upper Cretaceous beds of Alaska are restricted, so far as we now know, to points on the Alaska Peninsula, on the Yukon, and possibly on the Anaktuvuk in northern Alaska. The lands were apparently growing and the seas narrowing after the close of Lower Cretaceous time.

None of the deposits of these Mesozoic epochs have been recognized in the Controller Bay region, or elsewhere on the Pacific coast between Cook Inlet and the Alexander Archipelago. This entire region may have been land during all of Mesozoic time, or it may be that erosion has removed the deposits. The possibility of Jurassic and other Mesozoic rocks underlying the Tertiary rocks of this region is discussed elsewhere. (See pp. 115–116.)

Areas of Tertiary rocks are widely scattered throughout all parts of Alaska, but the character of the deposits and other evidence, both physiographic and paleontologic, shows that these beds were laid down for the most part in or near estuaries and to some extent along rivers. The ocean extended over very little of what is now Alaska during Tertiary time. Large areas in many parts of Alaska were

[a] Jurassic rocks are known also at Cape Lisburne, but their exact stratigraphic position is uncertain.

exposed to long-continued erosion and were reduced at least to a non-mountainous condition before the middle of the Tertiary. Peneplains or at least broad areas of fairly low relief were developed.

The Tertiary deposits of Alaska are of four types: The marine Eocene, the Tertiary coal-bearing rocks,[a] the marine Miocene, and the marine Pliocene.

Marine Eocene deposits are known only at Stepovak Bay,[b] on the Alaska Peninsula, where they consist of terrestrial and volcanic detritus deposited in the sea and carrying marine fossils. They show that the ocean covered part of the Alaska Peninsula in Middle Eocene time and that volcanic agencies were active. Most of Alaska was doubtless land.

The Tertiary coal-bearing rocks cover large areas in many parts[c] of Alaska. They are known in southeastern Alaska, in the vicinity of Mount St. Elias, on Bering River, in the valley of Copper River, on Cook Inlet, in the Matanuska and Susitna valleys, on Kodiak Island, on Alaska Peninsula and the neighboring islands, throughout the valley of the Yukon and its tributaries, on the coasts of Bering Sea, and on the rivers of the Arctic slope. Not all the Tertiary coal-bearing rocks are of the same age, and the exact position of most of them is not very well known. It is probable that conditions favorable for the formation of coal existed in one part of Alaska or another during the greater part of Tertiary time.

Marine Miocene rocks occur at Cape Yaktag, Controller Bay, the Shumagin Islands, and other scattered places. They indicate that Miocene waters did not cover broad areas in Alaska, but were restricted to narrow arms of the sea.

Marine Pliocene rocks are apparently of very limited extent, the most important areas being at Lituya Bay and on the Arctic slope.

Returning to the interpretation of the local section, we find that marine conditions existed during much of the deposition of the Katalla formation. The Stillwater formation was laid down partly in the sea and probably in part in brackish or fresh water. The Kushtaka formation represents fresh-water conditions, probably in a shallow estuary or on a river. The transition from the Kushtaka to the Tokun formation represents the return of marine conditions, probably without unconformity. There is no evidence as to whether the upper part of the Tokun formation represents marine or fresh-water conditions. These four formations represent the local Tertiary

[a] This term includes rocks of considerable diversity of age, the exact position of some of which has not been determined.

[b] Palache, Charles, Geology about Chichagof Cove, Stepovak Bay: Harriman Alaska Expedition, vol. 4, 1902, pp. 69–88.

[c] Martin, A. C., The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 41–44. Brooks, Alfred H., Geography and geology of Alaska, Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 237–244.

sedimentation, and were probably all laid down during Oligocene and Miocene time. (See pp. 37–41.)

The folding of all these rocks took place in very late Tertiary time or in post-Tertiary time, and was probably accompanied by the intrusion of small dikes and sills of diabase and basalt. It has been suggested above (see p. 45) that this folding may have taken place in or on the border of the Chugach Mountains and was followed by the southward overthrusting of the vast mass of rocks to their present position on the ocean shore. The folding was accompanied or closely followed by uplift, which has probably continued intermittently until recent time. Orogenic movements are known to be still in progress along the western base of the Chugach Mountains on Yakutat Bay,[a] although none so recent have been detected at Controller Bay.

The uplift of the region has been accompanied by vigorous erosion. Several halts in the downcutting are recorded in the existing topographic forms. Each of the levels of accordant summits and hillside benches represents a time when the uplifting ceased and erosion reduced considerable areas to near base-level. Such periods existed when the land stood about 3,500, 3,000, 2,450, 2,000 to 2,100, 1,750 to 1,850, 1,450 to 1,500, 1,200 to 1,250, 950 to 1,050, 750 to 800, and 500 to 600 feet lower than at present. At some of these times the halt was of short duration and the streams merely widened their valleys a bit. At other times, as when the land stood 2,000 or 2,100 feet lower than now, the halt was long, and the greater part of the area of soft rocks was reduced to an even plain. The uplifting was then resumed and the rivers trenched the plain, destroying much of it, and sinking their channels deeper until the next halt in the uplift enabled them to widen their valleys again and produce new plains and terraces.

The upward movement thus continued intermittently until the land stood at least 600 feet and probably at least 1,000 feet higher than at present, when the now submerged and alluvium-filled valleys were cut. The succeeding movement was a depression of the land to near its present level.

At an unknown time during the Quaternary a movement along a fault on Wingham Island resulted in the elevation of a small body of unconsolidated marine sediments to a maximum height of about 100 feet above sea level. There was no general uplift at this time, and similar local movements are not known to have taken place in other parts of the Controller Bay region.

Glaciers invaded the region at an undetermined time and probably attained their maximum extent when the land stood about 1,000 feet higher than at present. This maximum extension represents a surprisingly small increase over the present development of the glaciers.

[a] *Tarr, R. S.*, and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1904, pp. 29–64.

The retreat of the glaciers to their present limits was probably brought about by the depression of the land to its present position. The glaciers are now probably melting slowly back, but their recession has probably not been rapid for a considerable time, and readvances, such as that which is now taking place in the Malaspina [a] and other glaciers in the vicinity of Yakutat Bay, are possible at any time.

The waters of Controller Bay extended over a large part of the present lowland area in very recent geologic time, and one of the latest episodes in the history of the region has been the filling of this greater Controller Bay by deposits from the heavily loaded glacial streams. It was this process which transformed Bering Lake from a salt-water bay into a fresh-water but tidal lake. This process is still going on with probably undiminished activity, and is now restricting Bering Lake and Controller Bay to shallower depths and narrower areas.

MINERAL RESOURCES.

COAL.

AREAL EXTENT.

The surface extent of the Bering River coal, as known at present, is restricted to the area of outcrop of the Kushtaka formation, as represented on the maps (Pls. V and VIII, pocket). The area of such territory which is believed to be underlain by workable coal is given below:

Areas underlain by coal.

	Square miles.
Anthracite and semianthracite:	
Carbon Mountain, north end	25.6
Carbon Mountain, south end	1.0
	26.6
Semibituminous (with some semianthracite):	
Between Canyon Creek and Kushtaka Glacier	8.7
Kushtaka Ridge and valley of Carbon Creek	3.6
Southeast of Lake Charlotte	.6
Southeast of Tokun Lake	2.6
North shore of Bering Lake	4.7
	20.2

In addition to this, 21.6 square miles, divided as in the following table, is covered at the surface by the rocks of the Tokun formation, which overlie the coal-bearing rocks and which are underlain by coal at a greater or less depth.

[a] Tarr, Ralph S., Second expedition to Yakutat Bay, Alaska: Bull. Geog. Soc. Philadelphia, January, 1907, pp. 1–14.

Areas covered at the surface by the Tokun formation, parts of which may be underlain by workable coal.

	Square miles.
North of Cunningham Ridge	4.2
Between Lake Charlotte and Kushtaka Glacier	5.6
Kushtaka Ridge, north end	.1
Kushtaka Ridge, south end	1.6
Northeast of Tokun Lake	2.8
South of Tokun Lake	2.7
Between Shepherd and Dick creeks	4.6
	21.6

Part of the area of this formation may contain workable coal, but the depth at which such coal will be found is in most places uncertain, and in much of the area it is known to be so deep that the coal can never be mined. The southern end of Carbon Mountain, colored on the map as "undifferentiated," is reported to contain some coal, but the area in this region is not known.

The coal is known to extend eastward beyond the area shown on the map into the high, glacier-covered mountains, but the boundaries of this extension are uncertain. The value of such coal is also doubtful because of the complexity of the structure and the difficulties of transportation. Coal has been reported as far as the vicinity of the eastern end of Bering Glacier, but the discovery has not been confirmed, nor the amount and character of the coal reported. No coal has been found west of the area represented as Kushtaka formation on the map. There is, however, a good possibility that areas of coal exist in the hills between Dick Creek and the north end of Ragged Mountain, and this region ought to be more carefully prospected.

STRATIGRAPHIC POSITION.

The coal beds are distributed throughout the entire thickness of the Kushtaka formation. They are also restricted to it, for both the overlying Tokun and the underlying Stillwater formation are entirely barren. The position of many of the beds is indicated in the stratigraphic sections on pages 32–34.

DESCRIPTION OF THE COAL BEDS.

The following pages contain measured sections of all the coal beds which were accessible either in natural exposures or in prospect openings or tunnels. The location of the sections is shown by the numbers, which correspond to those on the map (Pl. VIII, pocket). No attempt has been made to correlate the beds, as the complex structure, the abrupt changes in thickness, and the fact that most of the beds have not been actually traced from point to point, usually makes this impossible. The sections are arranged in order from *northeast to* southwest.

The exposures of anthracite at the extreme eastern end of the area mapped are for the most part well up the mountain sides and inaccessible. The following seams were measured and were also sampled when thus indicated:

Section on crest of Carbon Mountain 2½ miles north-northwest of Fourth Berg Lake (1).

	Feet.
Coal (hard and clean)	3

Section 1⅔ miles up creek from Fourth Berg Lake; elevation 1,850 feet (2).

	Ft.	in.
Dark shale roof.		
Coal [a]		8
Coaly shale		4
Coal [a]		11
Coaly shale		3
Coal [a]		8
Shale floor.		
	2	10

Strike N. 76° W., dip 55° SW.

About a mile above this on the north side of the valley and just below the hanging glacier a 7-foot bed of anthracite is reported. The sample shown to the writer is very bright, hard, and not crushed at all.

Section in gulch at head of Second Berg Lake (3).

	Ft.	in.
Sandstone roof.		
Coal, bony		6
Coal, hard and bright [b]	2	2
Sandy shale floor.		

Strike N. 85° W., dip 32° NE.

The best exposures of anthracite seen by the writer are in Carbon Mountain, where the following sections were measured:

Section in third (eastern) opening on hillside trail on east side of Carbon Mountain (4).

	Ft.	in.
Shale roof.		
Coal	10	6
Shale floor.		

Strike N. 60° E., dip 28° NW.

Section on east side of Carbon Mountain, second opening from west end of hillside trail (5).

	Feet.
Shale roof.	
Coal [c]	15+
Shale floor.	

Strike N. 77° E., dip 22° NW.

[a] Included in sample No. 2, p. 84. [b] Included in sample No. 3, pp. 84–87.
[c] Included in sample No. 5, pp. 84–87.

It was not possible to obtain a complete measurement of this coal, which is reported as being 23 to 25 feet thick.

Section on east side of Carbon Mountain, first opening from west end of hillside trail (6).

	Ft.	In.
Coal [a]	10	6

The above three sections are all probably on the same seam, which the owners claim to have followed along the mountain side for 2 miles, in which distance they found thickness ranging from 9 to 25 feet.

About 200 feet below this is another seam, which is said to vary in thickness from 4 to 11 feet. The following section was measured by the writer:

Section of seam 200 feet below hillside trail on east side of Carbon Mountain (7).

	Ft.	In.
Shale roof.		
Coal [b]	4	8
Shale floor.		

Strike N. 80° W., dip 30° NE.

Several other seams are exposed lower down the face of the mountain.

An important and apparently very persistent seam is exposed along the west side and near the top of Carbon Mountain. It is possibly the same as the upper seam, referred to above, on the east side of the mountain. The following sections were measured:

Section at north end of hillside trail on west side of Carbon Mountain (8).

	Feet.
Shale roof.	
Coal [c] (bright, clean, and often iridescent)	15+
Shale floor.	

Strike N. 84° W., dip 25° NE.

Section at south end of hillside trail on west side of Carbon Mountain (9).

	Feet.
Shale roof.	
Coal [d]	10
Shale floor.	

Strike N. 52° E., dip 6° SE.

The two following sections, which are a little farther south on the west side of the same ridge, show a coal which has the physical characteristics of the anthracite at the other openings in the vicinity, but whose analyses indicate a semianthracite. From the structural relations it seems probable that one of the seams corresponds to the lower coal described from the eastern side of the mountain.

[a] Included in sample No. 6, pp. 84–87.
[b] Included in sample No. 7, p. 84.
[c] Included in sample No. 8, pp. 84–87.
[d] Included in sample No. 9, pp. 84–87.

Section in opening near crest (west side) of Carbon Mountain between trails (10).

	Ft.	in.
Shale roof.		
Coal [a]	5	3
Shale floor.		

Section in opening 50 feet below No. 10 (11).

	Ft.	in.
Shale roof.		
Coal, impure		3
Coal [b] (good and hard)	2	10
Shale floor.		

Strike N. 82° E., dip 38° NW.

Numerous outcrops of anthracite (mostly poorly exposed) were seen on the banks of Canyon Creek for a distance of 2 or 3 miles below the glacier. The two following sections represent the best of these outcrops:

Section at source of Canyon Creek (west bank) (12).

	Feet.
Coal	5

Section on west bank of Canyon Creek, 500 feet below glacier (13).

	Feet.
Coal	3

Section on tributary to Canyon Creek, on east side and next below Hunt's cabin; elevation, 630 feet (14).

	Ft.	in.
Coal [c]	6	9

Strike N. 55° W., dip 31° NE.

Section on same creek as No. 14; elevation, 450 feet (15).

	Feet.
Shale roof.	
Coal	3
Shale floor.	

Strike N. 65° E., dip 60° NW.

Section on same creek as Nos. 14 and 15, about 100 feet above creek; elevation, 520 feet (16).

	Ft.	in.
Firm shale roof.		
Coal [d]	2	7
Shale floor.		

Strike N. 55° E., dip 46° NW.

Section in tunnel on east bank of Canyon Creek, near Hunt's cabin, 2¾ miles above mouth of creek (17).

	Ft.	in.
Shale roof.		
Coal [e]	4	2
Shale floor.		

Strike N. 40° E., dip 60° NW.

[a] Included in sample No. 10, pp. 84–87.
[b] Included in sample No. 11, pp. 84–87.
[c] Included in sample No. 14, pp. 84–87.
[d] Included in sample No. 16, pp. 84–87.
[e] Included in sample No. 17, pp. 84–87.

Section in east bank of Canyon Creek, 2 miles above its mouth (18).

	Ft.	in.
Sandstone roof.		
Coal	2	9
Shale floor.		

Strike N. 70° W., dip 35° NE.

This bed is very variable in thickness and pinches out higher in the bluff.

Section in creek on west slope of Carbon Mountain opposite the mouth of Canyon Creek; elevation, 950 feet (19).

	Ft.	in.
Shale.		
Coal	1	
Shale	1	
Coal [a] (ranges from 3 to 21 inches)	1	5
Shale (ranges from 1 to 18 inches)		1
Coal [a] (ranges from 14 to 24 inches)	1	2
Hard shale floor.		

Strike (on floor) N. 25° E., dip 53° NW. (variable).

Section on same creek as No. 19; elevation, 900 feet (20).

	Ft.	in.
Arkose roof.		
Coal [b] (ranges from 8 to 22 inches)	1	8
Arkose floor.		

Strike N. 90° E., dip 33° NW.

At the south end of Carbon Mountain there is a high bluff, where Bering River was formerly pushed against the end of the mountain by Bering Glacier, and here the following section was measured:

Section at south end of Carbon Mountain (21).

	Feet.
Sandstone	30
Coke	1
Sandstone and shale cut by diabase sills	20
Coke	2
Diabase sill	2–6
Coke [c]	1–5
Diabase sill	3
Coke	1
Diabase sill	8
Coke	1½–2½
Shale	120

Strike N. 50° W., dip. 20°–25° N.

The coke and sills at this point are shown in Pl. IX, *B* (p. 92).

The valley of Clear Creek contains many good exposures of semianthracite and semibituminous coal. The following sections represent part of the exposures and openings:

Section in small tunnel on north bank of Clear Creek; elevation, 750 feet (22).

	Ft.	in.
Shale roof.		
Coal	2	10
Shale floor.		

[a] *Included* in sample No. 19, pp. 84–87. [b] Included in sample No. 20, pp. 84–87.
[c] Included in sample No. 21, p. 84.

Section in tunnel on north bank of Clear Creek near top of falls (23).

	Feet.
Shale roof.	
Coal [a]	18
Shale floor.	

Section in stripping on northwest bank of Clear Creek above falls (24).

	Feet.
Coal	47

Section in stripping south of No. 24 (25).

	Feet.
Coal	31

Section at base of Clear Creek Falls (26).

	Feet.
Shale.	
Diabase sill.	
Coke (ranges from 6 to 12 inches)	1
Coal [b]	5
Coal	11
Shale.	

Strike N. 65° E., dip 45° NW.

This seam varies considerably in thickness within short distances. A measurement at the base of the falls showed 8 feet 2 inches of coal, while one at the tunnel a few yards away gave a total of about 16 feet.

Section on tributary to Clear Creek, heading southeast of Monument Mountain, elevation 1,450 feet (27).

	Ft.	in.
Firm shale roof.		
Coal	1	4
Hard shale		7
Soft shale with some coal	1	2
Shale	2	3
Coal [c]	3+	
Sandstone floor; fault at floor cuts off coal above it.		

Strike (on roof) N. 85° E., dip 32° NW.

Section on same creek as No. 27; elevation 1,200 feet (28).

	Ft.	in.
Firm shale roof.		
Coal [d]	1	10
Bone		4
Coal [d]		11
Bony coal		7
Coal [d]		3
Shaly coal		3
Coal [d]	3	3
Shale horse	5	
Shaly coal	2	
Coal	1	

Strike N. 67° E., dip 30° NW.

[a] Included in sample No. 23, pp. 84–87.
[b] Included in sample No. 26, pp. 84–87.
[c] Included in sample No. 27, pp. 84–87.
[d] Included in sample No. 28, pp. 84–87.

Section on east bank of Clear Creek, 2.9 miles above its mouth (29).

	Feet.
Flaggy sandstone.	
Sandy shale	3
Coal [a]	4
Diabase sill	4
Sandy shale.	

Strike N. 90° E., dip 67° N.

This is the lowest coal exposed on Clear Creek, although two lower ones are reported on a near-by tributary from the north. There is no physical evidence that the intrusion has altered the coal.

Section in prospect opening on crest of ridge between Trout and Clear creeks, south of Trail Gap; elevation 1,885 feet (30).

	Ft.	in.
Shale	1	
Coal		4
Shale		4
Coal	10	
Shale	1	
Coal	2	4
Shale	2	

Strike N. 70° E., dip 34° NW.

Section on crest of same ridge as No. 30, 500 feet farther south.

	Feet.
Shale, dark	12
Coal	12
Shale	8

Strike N. 70° E., dip 34° NW.

Several workable seams are exposed on Trout Creek. The following sections, arranged in stratigraphic order beginning with the highest, were measured:

Section in tunnel on Trout Creek opposite house (33).

	Feet.
Shale roof.	
Coal [b]	8
Shale floor.	

Strike N. 85° W., dip 28° NE.

Section at creek level below No. 33 (34).

	Ft.	in.
Shale	4	
Coal [c]	6	6
Sandstone	5	

Strike N. 70° E., dip 38° NW.

Section in long tunnel one-fourth mile below house on Trout Creek (36).

	Ft.	in.
Coal	4	6

[a] Included in sample No. 29, pp. 84–87. [b] Included in sample No. 33, pp. 84–87.
[c] Included in sample No. 34, p. 84.

Section in long tunnel one-fourth mile below house on Trout Creek (136).

	Feet.
Shale roof.	
Coal[a]	33
Shale floor.	

Strike N. 65° E., dip 38° NW.

Section in tunnel 1,500 feet below house on Trout Creek (37)

	Ft.	in.
Arkose roof.		
Coal	7	7
Arkose floor.		

Section on small drain into Trout Creek from the west, near mouth of Bear Creek; elevation 395 feet (38).

	Feet.
Shale roof.	
Coal	6
Shale floor.	

Strike N. 2° W., dip 24° SW.

Section on same drain as No. 38; elevation 375 feet (39).

	Ft.	in.
Coal	3	6

Strike N. 25° E., dip 39° NW.

Section on same drain as Nos. 38 and 39; elevation 360 feet (40).

	Feet.
Shale roof.	
Coal	12+
Shale floor.	

Strike N. 15° E., dip 27° NW.

The following sections are all on the east slope of Kushtaka Ridge:

Section on east side of Kushtaka Ridge, one-fourth mile east of U. S. L. M. Kayak No. 4 (41).

	Feet.
Shale	30
Coal	5
Coal and shale	5
Shale	10
Coal	3
Shale floor.	

Strike N. 38° E., dip 70° NW.

Section on east side of Kushtaka Ridge, elevation 1,630 feet (42).

	Ft.	in.
Shale roof.		
Bone		8
Coal	3	8
Shale		1
Coal	3	4
Bone		3
Coal	1	8

[a] Included in sample No. 36, pp. 84–87.

	Ft.	In.
Bone		5
Coal	1	
Shale		4
Coal		11
Bone		2
Dark shale floor.	12	6

Strike N. 45° E., dip 68° NW.

Section on Kushtaka Ridge, east side, 1½ miles north-northwest of cabin; elevation 1,600 feet (43).

	Feet.
Shale roof.	
Coal [a]	14
Shale floor.	

Section on Kushtaka Ridge, east side, 1 mile north northwest of cabin; elevation, 850 feet (44).

	Feet.
Soft shale roof.	
Coal [b]	3
Soft shale floor.	

Strike N. 77° E., dip 40° NW.

Section on east side of Kushtaka Ridge; elevation, 1,335 feet (45).

	Ft.	In.
Coal	12–15	
Shale	1	
Coal	2	6
Shale	2	6
Bone	2	1
Coal	2	6
Bone		6
Coal	1	
Bone		4
Coal	2	6
	27–30	2

Strike N. 22° E., dip 58° NW.

Section in tunnel on trail 2,200 feet north of Kushtaka cabin (46).

	Feet.
Shale roof.	
Coal (pinching out)	10

Strike N. 25° E., dip 42° NW.

Section in tunnel on east face of Kushtaka Ridge; elevation, 790 feet (48).

	Ft.	In.
Firm shale roof.		
Coal [c] somewhat bony and with pyrite nodules	14	6
Hard shale floor.		

Strike N. 65° E., dip 45° NW.

[a] Included in sample No. 43, pp. 84–87. [b] Included in sample No. 44, pp. 84–87.
[c] Included in samples Nos. 48a and 48b, pp. 84–87.

The following sections are exposed on the crest of Kushtaka Ridge, beginning near United States locating monument Kayak No. 4 and extending for about one-half mile southeast. The stratigraphic position of the beds is given in the section on pages 32–34.

Section on Kushtaka Ridge just below U. S. L. M. Kayak No. 4; elevation, 2,400 feet (49).

	Ft.	in.
Shale.		
Coal	2	2
Coal, shaly	1	
Shale	9	
Coal	4	8
Shale.		

Strike N. 45° E., dip 64° NW.

Section on Kushtaka Ridge 500 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,340 feet (50).

	Ft.	in.
Shale, carbonaceous	2	
Coal	2	3
Shale, carbonaceous		5

Strike N. 45° E., dip 65° NW.

Section on Kushtaka Ridge 1,300 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,180 feet (51).

	Ft.	in.
Shale	7	
Coal	3	
Shale		6
Coal		6
Shale		6
Coal	1	
Shale	2	

Strike N. 45° E., dip 45° NW.

Section on crest of Kushtaka Ridge, 1,400 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,150 feet (52.)

	Ft.	in.
Sandy shale	2	
Shale with coal streaks	2	8
Coal	8	8
Soft shale floor	1	

Strike N. 40° E., dip 40° NW.

Section on Kushtaka Ridge, 1,700 feet southeast of U. S. L. M. Kayak, No. 4; elevation, 2,100 feet (53).

	Feet.
Shale with coal streaks	5
Coal	1
Shale	2
Coal	5
Shale.	

Strike N. 40° E., dip 45° NW.

The following sections are on the west slope of Kushtaka Ridge, in the valley of Carbon Creek:

Section on north bank of Carbon Creek, near headwaters; elevation 1,350 feet (54).

	Ft.	in.
Shale	1	
Coal	2	8
Shale		4
Coal	1	11
Shale	1	

Strike N. 18° E., dip 30° NW.

Section of coal on northwest bank of Queen Creek (55).

	Feet.
Shale roof.	
Coal[a]	27
Shale (pocket?)	7
Coal	2
Shale	10
Coal[b]	31
Shale floor.	77

Strike N. 64° E., dip 42° NW.

Section of coal on southeast bank of Queen Creek (56).

	Ft.	in.
Coal	14	
Shale	4	
Coal	7	
Shale		3
Coal	2	
Shale		2
Coal	10	

Strike N. 66° E., dip 58° SE.

Section on small creek southwest of Queen Creek (57).

	Ft.	in.
Shale roof.		
Coal	1	1
Shale	3	6
Coal	2	2
Shale with coal streaks	1	6
Coal	3	6
Shale		8
Coal	6	8
Shale	3	6
Coal	11	
	33	7

[a] Included in samples Nos. 55a and 55b, pp. 84–87.
[b] Included in samples Nos. 55c and 55d, pp. 84–87.

Section on small creek southwest of Queen Creek (58).

	Ft.	in.
Shale roof.		
Coal[a]	17	
Shale	41	
Coal	4	
Shale	5	
Coal	3	
Shale	2	6
Coal	26	
Carbonaceous shale.		
	98	6

Section on small creek southwest of Queen Creek (59).

	Feet.
Coal	14
Shale	2
Coal	16
	32

Section on Leeper Creek, one-third mile above its mouth (60).

	Feet
Coal[b]	8–11

Strike N. 40° E., dip 75° NW.

Section in stripping on north side of Carbon Creek above the tunnel and at an elevation of 830 feet (61).

	Feet.
Shale roof.	
Coal	8
Shale floor.	

Strike N. 50° E., dip 45° NW.

Section in tunnel on south bank of Carbon Creek (62).

	Feet.
Arkose roof.	
Coal[c]	8–11
Shale floor.	

Section in tunnel near mouth of Nevada Creek (64).

	Ft.	in.
Dark shale	2	
Coal[d]	19	7
Arkose		10

Strike N. 90° E., dip 78° N.

The following sections are in the upper part of the valley of Shepherd Creek, above the mouth of Carbon Creek:

[a] Included in sample No. 58, pp. 84.
[b] Included in sample No. 60, pp. 84–87.
[c] Included in samples Nos. 62a and 62b, pp. 84–87.
[d] Included in samples Nos. 64a and 64b, pp. 84–87.

Section at north end of upper trail on east side of Lake Charlotte; elevation 810 feet (65).

	Ft.	In.
Shale roof	10	
Coal		2
Shale		5
Coal[a] with many thin partings of bone	9	6
Shale and coal	6	

Strike N. 12° E., dip 72° SE.

At this opening the coal is firm and should stand shipment with less crushing than many of the others in this field, but the amount of ash is excessive. The same seam has been opened again about half a mile south of this point.

Section of prospect opening near Grade Trail cabin ("Doyle camp") on east side of Shepherd Creek, 1¼ miles below Lake Charlotte (66).

	Ft.	In.
Shale roof.		
Coal	20	6
Shale floor.		

Strike N. 40° E., 75°-85° NW.

This bed, which appeared very promising when first opened, showing a great thickness of beautiful, clean coal, has been found to be cut off entirely within a few feet by a fault.

The following section is the only one measured in the lower part of the Shepherd Creek valley, although a considerable area of coal is known:

Section 1 mile northwest of Canoe Landing on Shepherd Creek; elevation 200 feet (67).

	Ft.	In.
Coal[b]	3	
Shale		2
Coal[b]	4	4

Strike N. 50° E., dip 65° NW.

The opening is on the west side of the valley of Shepherd Creek, at an elevation of about 200 feet above Bering Lake.

The following sections are in the valley of Lake Tokun:

Section in prospect opening on west bank of Tokun Creek, 1¼ miles above Lake Tokun (68).

	Feet.
Arkose roof.	
Coal	2
Shale floor.	

Strike N. 65° E., dip 33° NW.

Section in prospect opening a short distance above No. 68 (69).

	Feet.
Arkose roof.	
Coal	3
Shale floor.	

Strike N. 65° E., dip 33° NW.

[a] Included in sample No. 65, p. 84.

[b] Included in sample No. 67, p. 84.

Section in lower tunnel on Tokun Creek, about 100 yards above No. 69 (70).

	Ft.	in.
Arkose roof.		
Coal [a]	6	8
Shale floor.		

Section in upper tunnel on Tokun Creek (71).

	Feet.
Sandstone, shaly.	
Coal	6
Strike N. 78° W., dip 40° NE.	

Section at head of gorge on Trail Creek (72).

	Ft.	in.
Sandstone roof.		
Coal	2	6
Sandstone floor.		
Strike N. 15° W., dip 55° NE.		

The coal in the valley of Dick Creek is represented in the following sections:

Section in tunnel on tributary to Dick Creek from the east 1½ miles above mouth of Dick Creek (73).

	Feet.
Coal	6
Sandstone floor.	
Strike N. 15 W., dip 60° NE.	

Section in tunnel on Powers Creek, 1 mile north of Bering Lake (74).

	Ft.	in.
Coal (top concealed)	2	
Shale	1	6
Coal [b]	8	6
Sandstone floor.		
Strike N. 70° E., dip 35° NW.		

Section on tributary to Falls Creek, ½ mile northeast of Christopher's cabin; elevation, 200 feet (75).

	Ft.	in.
Soft shale with probably a little overlying coal.		
Coal [c]	2	7
Shale		7
Coal		9
Shale	1	10
Coal		5
Coaly shale		6
Arkose.		
Strike N. 25° E., dip 60° SE.		

Section in opening in cliffs of Falls Creek, 1 mile north of Bering Lake; elevation, 110 feet (76).

	Feet.
Arkose.	
Coal [d]	3
Coal and shale	3
Coal [d]	4
Sandy shale floor.	
Strike N. 20° W., dip 25° NE.	

[a] Included in sample No. 70, p. 84.
[b] Included in sample No. 74, p. 84.
[c] Included in sample No. 75, pp. 84–87.
[d] Included in sample No. 76, pp. 84–87.

Up the creek from this point are numerous small surface openings each showing from 2 to 3 feet of irregular coal:

Section on Falls Creek 1 mile above its mouth; elevation, 800 feet (77).

	Feet.
Massive arkose.	
Coal	6
Shale	4
Coal	2+

Strike N. 46° E., dip 35° NW.

Section on ridge south of Mount Hamilton; elevation, 1,625 feet (78).

	Feet.
Coal	1
Shale	1
Coal	12½
Shale	1
Coal	2

Strike N. 80° W., dip 85° NE.

Section on ridge south of Mount Hamilton; elevation, 1,550 feet (79).

	Ft.	in.
Arkose.		
Shale	3	
Coal	7	
Shale		9
Coal	2	
Shale	3	

Strike N. 89° E., dip 40° NW.

Section in gulch two-fifths of a mile southwest of Mount Hamilton; elevation, 1,100 feet (80).

	Ft.	in.
Shale roof.		
Coal [a]	5	
Shale at top and bottom, concealed between	30	
Coaly shale	2	
Coal [b] (somewhat impure)	1	5
Shale		2
Coal [b] with shale streaks	1	4
Shale		4
Coal [b] with little shale	1	
Shaly coal		6
Coal [b]		9
Shale	1	
Coal, impure		4
Coal [c]	1	8
Shale		2
Coal [c]	4	6
Shaly sandstone floor.		

Strike N. 40° E., dip 52° NW.

[a] Included in sample No. 80a, pp. 84–87. [b] Included in sample No. 80b, pp. 84–87.
[c] Included in sample No. 80c, pp. 84–87.

Section in tunnel on shore of Bering Lake halfway between Poul Point and mouth of Dick Creek (81).

	Ft.	in.
Shale roof.		
Coal		8
Sandstone	1	
Coaly shale		10
Coal [a]	4	
Soft shale		6

Possibly some coal beyond.
Strike N. 76° E., dip. 72° NW.

CHARACTER OF THE COAL.

PHYSICAL PROPERTIES.

Numerous specimens of hard, firm, bright, and apparently pure coal, possessing all the physical characteristics of the best anthracite, have been seen in the upper part of the valley east of Carbon Mountain.

These properties are not evident in most of the surface exposures of the coal beds and in the shallow openings, such exposures usually showing only a soft, weathered mass of coal which gives little indication of anthracite character. However, in all parts of the region indicated on the map (Pl. VIII) as containing anthracite float specimens of good anthracite, such as those described above, are found, and the best of the natural and artificial exposures of the coal beds contain some fragments which indicate that the unweathered coal would be of the anthracite character of the hard float specimens. The classification of all the coal of this part of the field as anthracite is furthermore confirmed (see pp. 90–91) by the other properties of the coal.

It is, however, not certain that this coal, though anthracite, will have the value to be expected from its composition. It is impossible to tell, from the present surface exposures, whether beds exposing a soft friable mass of weathered coal will be found hard and unbroken below the zone of surface disintegration, or whether this coal is all badly crushed and shattered. The value of this end of the field, as determined by the possibility of profitable mining, depends largely on this question, for when an anthracite is badly crushed its market value is far more seriously impaired than that of a bituminous coal would be.

The coal of the rest of the region, classed below as semianthracite and semibituminous coal, is all of a friable nature, the least crushed of it somewhat resembling part of the softer bituminous coals of the Eastern States. Many of the beds have been severely crushed and sheared, and the coal is certain to be badly broken up in mining and

[a] Included in sample No. 81, pp. 84–87.

shipping, thus yielding a large proportion of slack. This is not such a great detriment in the case of the semibituminous coking coal as it is with the anthracite and semianthracite, for, as will be shown below some of it will probably be made into coke, while that which is used as steam coal will fuse and cake as soon as it is put into the furnace, thus preventing the loss of slack through the grates.

COMBUSTION.

The coal from all parts of the field burns with short flame and little or no smoke, the length of flame and amount of smoke being least in the coal from the eastern part of the field and increasing gradually westward. The coal from the west end of the field fuses and cakes somewhat on beginning to burn, but that from the eastern part burns without caking. Considerable fine coal or coke usually goes through the grate without burning, but this could be remedied by the use of finer grates than are customarily used in this region. The ashes are soft and fine and little or no clinker is formed.

COKING TESTS.

The coking qualities of the coal from the 33-foot bed on Trout Creek (see tunnel No. 36 on Pl. VIII, pocket, and on p. 73) were tested by the writer in the summer of 1905 in the following manner: A hot wood fire was built in a pit dug for the purpose, and lump coal gradually added until about 600 pounds of coal was burning. Then about a ton of slack and lump coal was added. The sides of the pile were banked with stones and dirt, the top and ends being left open for draft. After several hours the ends were banked and only a small opening at the top was left uncovered to let the smoke escape. Four days later, when the smoke ceased to come off, the pile was opened and the fire extinguished. The resulting coke was firm, strong, porous, and had a good ring and luster. The test showed conclusively that an excellent coke can be made from this coal by proper treatment.

The coal from the 8-foot bed on Carbon Creek (see tunnel No. 62 on Pl. VIII, pocket, and on p. 77) was tested in 1906 in the same manner. Heavy rains, during the early part of the test, made it impossible to get as hot a fire as should have been used, and the test was consequently not as great a success as was hoped for. A small quantity of fair quality of coke was obtained from the center of the pit, which seems to indicate that, under more favorable conditions, good coke could be produced.

Coal from many of the other seams was tested more crudely, and it was found that practically all of the coal here classed as semibituminous possesses such coking qualities that probably by proper treatment a good coke can be made from almost any of it.

CHEMICAL AND CALORIMETRIC PROPERTIES.

ANALYSES AND CALORIMETER TESTS.

Methods of sampling.—The analyses and calorimeter tests recorded in the tables on pp. 84–87 were made upon samples collected by the writer. These samples were all collected in the following manner: A position was selected where a complete and characteristic section of the bed was exposed, and where the effects of weathering were absent or as slight as possible. A fresh cut was then made across the bed from roof to floor, cleaning off all dirt and weathered coal as far as possible. A waterproof cloth was spread to catch the coal, and a sample was cut from the roof to the floor, taking all parts of the bed alike, except such shale and other bedded impurities as could readily be separated in the ordinary practices of actual mining. The parts of each bed which went into the sample are indicated in the local sections. The sample was then pulverized and carefully quartered. A 3-pound sample prepared in this way was sealed immediately in an air-tight can [a] which was not opened until the coal was analyzed.

Methods of analysis.—The samples collected in 1905 and 1906 were analyzed by F. M. Stanton of the United States Geological Survey fuel-testing plant at St. Louis, Mo., using the standard methods [b] adopted in that work. The samples collected in 1904 were analyzed by E. C. Sullivan of the United States Geological Survey. The samples collected in 1903 were analyzed and the calorific value determined by Penniman & Browne, of Baltimore, Md. The methods were the same as those used [c] for the Maryland Geological Survey.

It will be noticed that most of these samples contained a large proportion of total moisture, the greater part of which was driven off by air drying.[d] Under most circumstances this proportion would be regarded as excessive and not characteristic of fair samples. But in view of the large amount of underground water which the rocks of this region contain, and the heavy rainfall, it seems probable that the total moisture of these analyses will represent approximately the proportion which the coal will contain in uncovered cars when it reaches tide water.

Analyses.—The table on page 84 contains proximate analyses of all the samples collected by the writer, and also calorimeter tests where such were made. Averages of all the analyses of each kind of coal are also given.

---

[a] Samples No. 55b, 55d, 62b, and 65 were shipped in canvas sacks, and consequently had a chance to dry in shipment. They were otherwise treated as described above.

[b] Bull. U. S. Geol. Survey No. 261, 1905, pp. 19–20; Prof. Paper U. S. Geol. Survey No. 48, 1906, pt. 1, 177–193; Bull. U. S. Geol. Survey No. 290, 1906, pp. 29–30.

[c] Penniman, W. B. D., and Browne, Arthur L., The chemical and heat-producing qualities of Maryland coals: Maryland Geol. Survey, vol. 5, 1905, pp. 620–625.

[d] Bull. U. S. Geol. Survey No. 261, 1905, pp. 19–20; Bull. U. S. Geol. Survey No. 290, 1906, pp. 29–30.

Analyses and tests of Bering River coals.—I.

Sample No.[a]	Laboratory No.	Thickness of coal, in feet.	Proximate analysis.						Calorific value.		Fuel ratio.
			Loss on air drying.	Total moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Calories.	British thermal units.	
[b] 2	2478	2.63	4.70	7.67	5.78	66.03	20.52	2.90	.....	.....	11.42
[b] 3	2485	2.17	1.90	3.74	5.41	85.92	4.93	1.10	.....	.....	15.83
[b] 5	2480	15+	6.10	8.33	6.36	82.00	3.31	1.11	.....	.....	12.89
[b] 6	2483	10.5	13.20	13.89	5.01	73.87	7.23	.82	6,743	12,137	14.75
[b] 7	2487	4.7	6.20	7.26	6.64	75.89	10.21	1.27	.....	.....	11.43
[b] 8	2496	15	5.20	5.93	6.76	81.47	5.84	.82	.....	.....	12.05
[b] 9	2882	10	7.00	8.31	7.12	82.43	2.14	1.05	.....	.....	11.58
([c])	.....	.....	.....	7.88	6.15	78.23	7.74	1.30	.....	.....	12.86
[b] 10	2481	5.25	5.00	7.94	9.20	78.53	4.33	.79	.....	.....	8.54
[b] 11	2479	2.85	1.50	4.43	10.14	80.78	4.65	.51	7,578	.....	7.97
[d] 14	4461	6.75	6.00	7.77	7.40	75.59	9.24	.66	6,983	12,569	10.21
[d] 16	4433	2.58	6.20	7.43	6.86	71.35	14.36	.57	6,606	11,891	10.40
[e] 17	.....	4.17	.....	3.24	9.79	62.97	24.00	1.94	6,502	.....	6.43
[d] 19	4462	2.67	5.30	7.64	9.82	76.31	6.23	.57	7,255	13,059	7.77
[d] 20	4459	1.67	1.80	2.95	6.81	75.74	14.50	1.08	7,104	12,787	11.12
[e] 21	.....	5	.....	1.34	6.30	84.57	7.79	.77	.....	.....	13.43
[d] 23	4431	18	5.00	5.71	8.75	80.89	4.65	1.22	7,881	14,186	9.24
[d] 26	4435	5	3.30	4.19	8.71	84.60	2.50	1.42	8,091	14,564	9.71
[d] 27	4460	3	5.50	6.59	9.21	71.53	12.67	.60	6,860	12,348	7.77
[d] 28	4430	7.42	4.80	5.89	10.86	78.41	4.84	2.50	7,539	13,570	7.22
([f])	.....	.....	.....	5.80	8.87	76.06	9.27	1.08	.....	.....	8.77
[d] 29	4451	4	2.40	3.69	13.17	77.10	6.04	3.08	7,751	13,952	5.85
[b] 33	2489	8	1.30	2.11	16.58	79.68	1.63	.78	.....	.....	4.81
[e] 34	.....	6.17	.....	2.36	18.12	71.87	7.65	.73	7,819	.....	3.97
[b] 36	2484	33	5.40	6.34	14.29	69.55	9.82	.64	.....	.....	4.87
[d] 43	4428	14	8.00	9.37	12.99	74.02	3.62	.63	7,424	13,363	5.70
[d] 44	4455	3	3.80	5.43	13.12	79.65	1.80	.67	8,025	14,445	6.07
[b] 48a	2497	14.5	1.90	2.68	11.06	73.31	12.95	5.27	.....	.....	6.63
[d] 48b	4463	14.5	1.30	2.92	10.74	71.32	15.02	4.14	6,859	12,346	6.64
[b] 55a	2486	27	3.00	4.23	14.03	79.75	1.99	.96	.....	.....	5.68
[g] 55b	.....	27	.....	.56	16.61	78.71	4.12	1.25	.....	.....	4.74
[b] 55c	2495	31	4.60	5.66	13.65	76.81	3.88	.77	.....	.....	5.63
[g] 55d	.....	31	.....	1.20	17.28	77.69	3.83	.78	.....	.....	4.49
[b] 58	2494	17	3.90	4.94	13.34	77.29	4.43	.83	.....	.....	5.79
[d] 60	4453	8	3.20	4.01	12.46	77.47	6.06	1.11	7,873	14,171	6.22
[b] 62a	2492	11	3.70	4.22	13.37	78.80	3.61	1.56	.....	.....	5.89
[g] 62b	.....	11	.....	.38	16.97	77.48	5.17	1.02	.....	.....	4.57
[b] 64a	2491	19.6	5.40	5.95	13.01	76.12	4.92	.61	.....	.....	5.85
[e] 64b	.....	19.6	.....	2.41	15.03	79.24	3.32	.51	8,345	.....	5.27
[g] 65	.....	9.5	.....	.68	17.87	60.73	20.72	.55	.....	.....	3.40
[e] 67	.....	7.5	.....	1.54	14.58	72.99	10.89	.69	7,664	.....	5.01
[b] 70	2490	6.67	3.70	4.35	11.97	73.34	10.34	1.13	.....	.....	6.13
[b] 74	2493	8.5	5.10	5.84	11.74	60.21	22.21	3.36	.....	.....	5.13
[d] 75	4454	2.58	3.90	5.51	12.85	64.34	17.36	2.83	6,513	11,723	5.01
[b] 76	2488	7	5.20	6.03	12.98	78.40	2.59	.70	.....	.....	6.04
[d] 80a	4437	5	5.20	7.74	15.57	67.83	8.86	.84	6,969	13,544	4.36
[d] 80b	4452	5.5	2.70	5.71	13.04	47.10	34.15	6.47	4,659	8,386	3.61
[d] 80c	4436	6.3	4.20	6.12	11.72	51.11	31.05	5.25	5,038	9,068	4.36
[d] 81	4427	4	4.60	5.14	13.90	75.96	5.00	1.16	7,814	14,065	5.46
([h])	.....	.....	.....	4.18	14.00	72.42	9.39	1.73	.....	.....	5.28

[a] These numbers agree with the section numbers given on Pl. VIII and in the sections of coal beds. The arrangement is geographic from northeast to southwest.

[b] Sample collected by G. C. Martin, 1905; analysis by U. S. Geological Survey fuel-testing plant.

[c] Average of analyses 2–9 (anthracite).

[d] Sample collected by G. C. Martin, 1906; analysis by U. S. Geological Survey fuel-testing plant.

[e] Sample collected by G. C. Martin, 1903; analysis by Penniman & Browne, of Baltimore, Md.

[f] Average of analyses 10–28, exclusive of No. 21 (semianthracite).

[g] Sample collected by G. C. Martin, 1904; analysis by E. C. Sullivan, U. S. Geological Survey.

[h] Average of analyses 29–81 (semibituminous).

LOCALITIES.

[b] 2. 1⅞ miles above Fourth Berg Lake.
[b] 3. Gulch at head of Second Berg Lake.
[b] 5. Carbon Mountain, east side, second opening from west on hillside trail.
[b] 6. Carbon Mountain, east side, first opening from west on hillside trail.
[b] 7. Carbon Mountain, east side, 200 feet below hillside trail.
[b] 8. Carbon Mountain, west side, north end of hillside trail.
[b] 9. Carbon Mountain, west side, south end of hillside trail.
[b] 10. Carbon Mountain, west side, near crest at trail.
[b] 11. Carbon Mountain, west side, 50 feet below the last.
[d] 14. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 630 feet.
[d] 16. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 520 feet.
[e] 17. Tunnel on east bank of Canyon Creek, 2⅞ miles above mouth of creek, near Hunt's cabin.
[d] 19. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 950 feet.
[d] 20. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 900 feet.
[e] 21. Carbon Mountain, south end (natural coke).
[d] 23. Tunnel on north bank of Clear Creek above the falls.
[d] 26. Tunnel at base of Clear Creek Falls.
[d] 27. Opening on tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,450 feet.
[d] 28. Opening on tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,200 feet.
[d] 29. Opening on east bank of Clear Creek, 2.9 miles above the mouth of the creek.
[b] 33. Trout Creek, tunnel opposite house.
[e] 34. Trout Creek, opening at creek level below the last.
[b] 36. Trout Creek, tunnel one-fourth mile below house.
[d] 43. Opening on Kushtaka Ridge, east side, 1½ miles north-northwest of cabin, elevation 1,600 feet.
[d] 44. Opening on Kushtaka Ridge, east side, 1 mile north-northwest of cabin, elevation 850 feet.
[b] 48a. Tunnel on east face of Kushtaka Ridge, elevation 790 feet.
[d] 48b. Tunnel on east face of Kushtaka Ridge, elevation 790 feet (same tunnel and seam as last).
[b] 55a. Opening on northwest bank of Queen Creek, upper bed.
[e] 55b. Opening on northwest bank of Queen Creek, upper bed (same as the last).
[b] 55c. Opening on northwest bank of Queen Creek, lower bed.
[e] 55d. Opening on northwest bank of Queen Creek, lower bed (same as the last).
[b] 58. Opening on small creek southwest of Queen Creek.
[d] 60. Tunnel on Leeper Creek, one-third mile above its mouth.
[b] 62a. Tunnel on south bank of Carbon Creek.
[e] 62b. Tunnel on south bank of Carbon Creek (same as the last).
[b] 64a. Tunnel near mouth of Nevada Creek.
[e] 64b. Tunnel near mouth of Nevada Creek (same as the last).
[e] 65. Opening at north end of upper trail on east side of Lake Charlotte, elevation 810 feet.
[e] 67. Tunnel 1 mile northwest of Canoe Landing on Shepherd Creek, elevation 200 feet.
[b] 70. Lower tunnel on Tokun Creek.
[b] 74. Tunnel on Powers Creek, 1 mile north of Bering Lake.
[d] 75. Tributary to Falls Creek, one-half mile northeast of Christopher's cabin, elevation 200 feet.
[b] 76. Cliffs on Falls Creek, 1 mile north of Bering Lake, elevation 110 feet.
[d] 80a. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, upper bed.
[d] 80b. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, upper bench.
[d] 80c. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, lower bench.
[d] 81. Tunnel on shore of Bering Lake, halfway between Poul Point and Dick Creek.

Analyses and tests of Bering River coals.—II.

SAMPLES AS RECEIVED.

Sample No.[a]	Laboratory number.	Thickness of coal in feet.	Proximate analysis.				Ultimate analysis.						Calorific value.	
			Loss on air drying.	Total moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
[b]3	2485	2.17	1.90	3.97	4.41	86.54	5.08	1.10	3.54	81.60	1.36	7.32	7,590	13,662
[b]5	2480	15+	6.10	8.01	6.01	82.47	3.51	1.11	4.18	80.47	1.48	9.25	7,500	13,500
[b]6	2483	10.5	13.20	14.30	4.50	73.74	7.46	.82	4.33	71.26	1.30	14.83	6,651	11,972
[b]8	2496	15	5.20	6.89	6.42	80.97	5.72	.82	4.08	79.80	1.37	8.21	7,463	13,433
[b]9	2882	10	7.00	8.52	5.76	83.20	2.52	1.05	4.02	81.46	1.45	9.50	7,619	13,714
([c])	.....	.....	.....	8.34	5.42	81.38	4.86	.98	4.03	78.92	1.39	9.82	7,365	13,258
[b]10	2481	5.25	5.00	7.55	9.28	78.44	4.73	.79	4.19	76.51	1.41	12.37	7,309	13,156
[b]11	2479	2.85	1.50	4.34	9.19	81.61	4.86	.51	4.04	80.90	1.28	8.41	7,538	13,568
[d]14	4461	6.75	6.00	7.77	7.40	75.59	9.24	.66	4.07	73.99	1.41	10.63	6,983	12,569
[d]16	4433	2.58	6.20	7.43	6.86	71.35	14.36	.57	3.71	70.10	1.50	9.76	6,606	11,891
[d]19	4462	2.67	5.30	7.64	9.82	76.31	6.23	.57	4.43	77.30	1.45	10.02	7,255	13,059
[d]20	4459	1.67	1.80	2.95	6.81	75.74	14.50	1.08	3.69	74.09	1.18	5.46	7,104	12,787
[d]23	4431	18	5.00	5.71	8.75	80.89	4.65	1.22	4.28	81.55	1.26	7.04	7,881	14,186
[d]26	4435	5	3.30	4.19	8.71	84.60	2.50	1.42	4.35	84.01	1.45	6.27	8,091	14,564
[d]27	4460	3	5.50	6.59	9.21	71.53	12.67	.60	4.30	72.45	1.30	8.68	6,860	12,348
[d]28	4430	7.42	4.80	5.89	10.86	78.41	4.84	2.50	4.31	78.19	1.33	8.83	7,539	13,570
([e])	.....	.....	.....	6.01	8.69	77.45	7.86	.99	4.14	76.91	1.36	8.75	7,317	13,170
[d]29	4451	4	2.40	3.69	13.17	77.10	6.04	3.08	4.20	79.99	1.44	5.25	7,751	13,952
[b]33	2489	8	1.30	1.96	15.95	80.13	1.96	.78	5.04	86.68	1.57	3.97	8,652	15,574
[b]36	2484	33	5.40	6.26	13.28	69.74	10.72	.64	4.22	74.51	1.47	8.44	7,223	13,001
[d]43	4428	14	8.00	9.37	12.99	74.02	3.62	.63	4.87	77.19	1.22	12.47	7,424	13,363
[d]44	4455	3	3.80	5.43	13.12	79.65	1.80	.67	4.55	83.26	1.42	8.30	8,025	14,445
[d]48b	4463	14.5	1.30	2.92	10.74	71.32	15.02	4.14	3.68	70.10	1.09	5.97	6,859	12,346
[b]55a	2486	27	3.00	4.32	11.55	81.70	2.43	.96	4.07	83.55	1.56	7.43	8,088	14,558
[b]55c	2495	31	4.60	5.91	11.95	78.09	4.05	.77	4.35	79.68	1.46	9.69	7,626	13,727
[d]60	4453	8	3.20	4.01	12.46	77.47	6.06	1.11	4.35	79.87	1.34	7.27	7,873	14,171
[b]62a	2492	11	3.70	4.40	13.00	78.77	3.83	1.56	4.61	83.82	1.35	4.83	7,999	14,398
[b]64a	2491	19.6	5.40	6.10	12.26	76.20	5.44	.61	4.58	80.79	1.35	7.23	7,743	13,937
[d]75	4454	2.58	3.90	5.51	12.85	64.34	17.30	2.83	4.00	66.05	.96	8.86	6,513	11,723
[b]76	2488	7	5.20	6.16	12.65	77.87	3.32	.70	4.70	82.63	1.28	7.37	7,962	14,332
[d]80a	4437	5	5.20	7.74	15.57	67.83	8.86	.84	4.55	70.86	1.19	13.70	6,969	12,544
[d]80b	4452	5.5	2.70	5.71	13.04	47.10	34.15	6.47	3.34	46.97	.81	8.26	4,659	8,386
[d]80c	4436	6.3	4.20	6.12	11.72	51.11	31.05	5.25	3.62	51.23	.96	7.89	5,038	9,068
[d]81	4427	4	4.60	5.14	13.90	75.96	5.00	1.16	4.50	80.68	1.38	7.28	7,814	14,065
([f])	.....	.....	.....	5.34	12.95	72.26	9.45	1.89	4.31	75.17	1.29	7.89	7,307	13,152

[a] These numbers agree with the section numbers as given on Pl. VIII and in the sections of coal beds (pp. 67–81). The arrangement is geographic from northeast to southwest.
[b] Sample collected by G. C. Martin, 1905; analysis by F. M. Stanton, U. S. Geol. Survey fuel-testing plant.
[c] Average of analyses 3–9 (anthracite).
[d] Sample collected by G. C. Martin, 1906; analysis by F. M. Stanton, U. S. Geol. Survey fuel-testing plant.
[e] Average of analyses 10–28 (semianthracite).
[f] Average of analyses 29–81 (semibituminous.)

LOCALITIES.

[b] 3. Gulch at head of Second Berg Lake.
[b] 5. Carbon Mountain, east side, second opening from west on hillside trail.
[b] 6. Carbon Mountain, east side, first opening from west on hillside trail.
[b] 8. Carbon Mountain, west side, north end of hillside trail.
[b] 9. Carbon Mountain, west side, south end of hillside trail.
[b] 10. Carbon Mountain, west side, near crest at trail.
[b] 11. Carbon Mountain, west side, 50 feet below the last.
[d] 14. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 630 feet.
[d] 16. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 520 feet.
[d] 19. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 950 feet.
[d] 20. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 900 feet.
[d] 23. Tunnel on north bank of Clear Creek, above the falls.

Analyses and tests of Bering River coals.—II—Continued.

AIR-DRIED SAMPLES (calculated from table on p. 86.)

Sample No.[a]	Proximate analysis.			Ultimate analysis.						Calorific value.		Indices of classification.		
	Moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.	Fuel ratio.	Carbon-hydrogen ratio.	Carbon-oxygen ratio.
[b]3	2.11	4.49	88.22	5.18	1.12	3.39	83.18	1.39	5.74	7,737	13,927	19.62	24.54	14.49
[b]5	2.03	6.40	87.83	3.74	1.18	3.73	85.70	1.57	4.08	7,987	14,377	13.72	22.98	21.00
[b]6	1.27	5.18	84.96	8.59	.94	3.30	82.10	1.50	3.57	7,662	13,793	16.39	24.85	23.00
[b]8	1.78	6.77	85.41	6.04	.86	3.69	84.18	1.45	3.78	7,872	14,170	12.61	22.81	22.27
[b]9	1.64	6.19	89.46	2.71	1.13	3.49	87.59	1.56	3.52	8,192	14,742	14.44	25.10	24.88
(e)	1.77	5.81	87.18	5.25	1.05	3.52	84.55	1.49	4.14	7,890	14,202	15.36	24.06	21.13
[b]10	2.68	9.77	82.57	4.98	.83	3.83	80.54	1.48	8.34	7,694	13,804	8.45	21.03	9.66
[b]11	2.89	9.33	82.85	4.93	.52	3.93	82.13	1.30	7.19	7,652	13,774	8.88	20.90	11.42
[d]14	1.88	7.87	80.42	9.83	.70	3.62	78.71	1.50	5.64	7,429	13,371	10.21	21.74	13.96
[d]16	1.31	7.31	76.07	15.31	.61	3.22	74.73	1.60	4.53	7,043	12,677	10.40	23.21	16.50
[d]19	2.47	10.37	80.58	6.58	.60	4.05	81.63	1.53	5.61	7,661	13,790	7.77	20.16	14.55
[d]20	1.17	6.93	77.13	14.77	1.10	3.55	75.45	1.20	3.93	7,234	13,021	11.12	21.25	19.20
[d]23	.75	9.21	85.15	4.89	1.28	3.93	85.84	1.33	2.73	8,296	14,933	9.24	21.84	31.44
[d]26	.92	9.01	87.49	2.58	1.47	4.12	86.88	1.50	3.45	8,367	15,061	9.71	21.09	25.18
[d]27	1.15	9.75	75.69	13.41	.63	3.90	76.67	1.38	4.01	7,259	13,067	7.77	19.66	19.12
[d]28	1.15	11.41	82.36	5.08	2.63	3.97	82.13	1.40	4.79	7,919	14,254	7.22	20.69	17.15
(e)	1.64	9.10	81.03	8.24	1.04	3.81	80.47	1.42	5.02	7,655	13,775	9.08	21.16	17.82
[d]29	1.32	13.49	79.00	6.19	3.16	4.03	81.96	1.47	3.19	7,942	14,295	5.85	20.34	25.69
[b]33	.67	16.16	81.18	1.99	.79	4.96	87.82	1.59	2.85	8,776	15,779	5.02	17.71	30.81
[b]36	.91	14.04	73.72	11.33	.68	3.83	78.76	1.55	3.85	7,635	13,743	5.25	20.56	20.46
[d]43	1.49	14.12	80.46	3.93	.68	4.33	83.90	1.33	5.83	8,070	14,525	5.70	19.38	14.39
[d]44	1.69	13.64	82.80	1.87	.70	4.29	86.55	1.47	5.12	8,342	15,016	6.07	20.17	16.90
[d]48b	1.64	10.88	72.26	15.22	4.20	3.58	71.02	1.10	4.88	6,949	12,509	6.64	16.91	14.55
[b]55a	1.36	11.91	84.22	2.51	.99	3.85	86.13	1.61	4.91	8,338	15,008	7.07	22.89	17.54
[b]55c	1.37	12.53	81.85	4.25	.81	4.02	83.52	1.53	5.87	7,994	14,389	6.53	20.78	14.23
[d]60	.84	12.87	80.03	6.26	1.15	4.12	82.51	1.38	4.58	8,133	14,639	6.22	20.03	18.02
[b]62a	.72	13.50	81.80	3.98	1.62	4.36	87.04	1.40	1.60	8,306	14,950	6.06	19.96	54.40
[b]64a	.74	12.96	80.55	5.75	.64	4.21	85.40	1.43	2.57	8,185	14,733	6.22	20.29	33.23
[d]75	1.68	13.37	66.95	18.00	2.95	3.71	68.73	1.00	5.61	6,777	12,199	5.01	18.53	12.25
[b]76	1.01	13.35	82.14	3.50	.74	4.35	87.16	1.35	2.90	8,398	15,108	6.15	20.04	30.06
[d]80a	2.68	16.42	71.55	9.35	.89	4.20	74.75	1.25	9.56	7,351	13,232	4.36	17.80	7.82
[d]80b	3.09	13.40	48.41	35.10	6.65	3.13	48.27	.83	6.02	4,788	8,619	3.61	15.42	8.01
[d]80c	2.01	12.23	58.35	32.41	5.48	3.29	53.48	1.00	4.34	5,259	9,466	4.36	16.26	12.32
[d]81	.57	14.57	79.62	5.24	1.22	4.18	84.57	1.45	3.34	8,191	14,744	5.46	20.23	25.32
(f)	1.40	13.50	75.29	9.82	1.96	4.03	78.33	1.34	4.53	7,614	13,703	5.62	19.19	20.94

LOCALITIES—Continued.

[d] 26. Tunnel at base of Clear Creek falls.
[d] 27. Tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,450 feet.
[d] 28. Tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,200 feet.
[d] 29. East bank of Clear Creek, 2.9 miles above its mouth.
[b] 33. Trout Creek, tunnel opposite house.
[b] 36. Trout Creek, tunnel one-fourth mile below house.
[d] 43. Kushtaka Ridge, east side, 1½ miles north northwest of cabin, elevation 1,600 feet.
[d] 44. Kushtaka Ridge, east side, 1 mile north northwest of cabin, elevation 850 feet.
[d] 48b. Tunnel on east face of Kushtaka Ridge, elevation 790 feet.
[b] 55a. Northwest bank of Queen Creek, upper bed.
[b] 55c. Northwest bank of Queen Creek, lower bed.
[d] 60. Tunnel on Leeper Creek, one-third mile above its mouth.
[b] 62a. Tunnel on south bank of Carbon Creek.
[b] 64a. Tunnel near mouth of Nevada Creek.
[d] 75. Tributary to Falls Creek, one-half mile northeast of Christopher's cabin, elevation 200 feet.
[b] 76. Cliffs on Falls Creek, 1 mile north of Bering Lake, elevation 110 feet.
[d] 80a. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, upper bed.
[d] 80b. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, upper bench.
[d] 80c. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, lower bench.
[d] 81. Tunnel on shore of Bering Lake, halfway between Poul Point and Dick Creek.

The tables on pages 84–87 contain proximate and ultimate analyses and calorimeter tests of the samples collected in 1905 and 1906. These analyses and tests were all made at the United States Geological Survey fuel-testing plant, under uniform methods and conditions, and are hence better adapted for comparison with one another than the other analyses. These proximate analyses (p. 84) of the samples collected in 1905 are not the same as the analyses of the same samples given in the other table (p. 86). No ultimate analyses were made until after the 1906 samples were collected, when ultimate analyses were made on both the 1905 and 1906 samples, and the proximate analyses on the former were repeated. The differences between the two sets of proximate analyses on the same samples represent the alteration in the coal samples which took place during the fifteen months that elapsed between the dates of the two analyses.

Phosphorus was not determined in any of the samples collected by the writer, but a group of 17 analyses made under private auspices show phosphorus[a] ranging from 0.003 to 0.070 and averaging 0.017. The exact localities of these samples, as well as the methods of sampling and analyses, are not known.

CLASSIFICATION OF THE COAL.

Schemes of classification.—Coal is classified according to its physical properties, behavior on burning, products of distillation, and chemical composition, into the main classes of anthracite, bituminous, and lignite. Further divisions include semianthracite and semibituminous, which are intermediate between anthracite and ordinary bituminous coal; coking coal, splint, block, and cannel, which represent special phases of bituminous coal; and subbituminous, which is intermediate between bituminous coal and lignite. The Bering River coal is all either anthracite, semianthracite, or semibituminous, so the basis of classification of only these will be considered here.

No one of the characteristics enumerated above forms a sufficient basis for the classification of coal, and since each class of coal probably grades completely across into other classes, it follows that if a large enough number and variety of coals are under consideration, no sharp divisions can be recognized even if all the properties are known. Yet, as a general thing, since some of these properties follow from certain others, a given coal can usually be referred to its approximate position without knowledge of all its properties. For example, anthracite can be recognized and distinguished from all the other classes by its physical appearance, by the way in which it burns, by the relative amounts of volatile hydrocarbons and nonvolatile carbon which it yields on distillation, and by its chemical composition. Semianthracite and semibituminous can not as a general thing be distinguished from each other by their physical appearance, but they

[a] Compare with phosphorus in Fairmont, West Virginia, coking coal, p. 111.

can be distinguished by the amount of flame and smoke, by the fact that semianthracite will not coke while semibituminous will coke, by the relative proportions of the products of distillation, and by chemical composition. Similarly semibituminous and bituminous coal can not usually be distinguished by physical appearance or by coking properties, but can be distinguished by the length of flame, by the amount of smoke, by the relative proportions of the products of distillation, and by the chemical composition.

It can be seen from the preceding paragraph that either the products of distillation or the chemical composition suffices for the recognition and separation of the classes of coal here represented.

The products of distillation are usually determined as moisture, volatile matter or "volatile hydrocarbons," fixed carbon, and ash; and the determination of them is called a "proximate analysis."[a] The relative proportion of the products of distillation is usually represented by the quotient of the fixed carbon divided by the volatile matter, or, as it is usually called, the fuel ratio, which is a convenient index of the classification of the coal. Fuel ratios which have been in use for the last sixty-five years or more were made the basis of a coal classification which was proposed by Frazer[b] in his work for the Second Pennsylvania Survey and which has come into quite general use, though with some modification of the limits of the various classes.

As originally stated by Frazer the fuel ratios of anthracite ranged from 100 to 12, of semianthracite from 12 to 8, of semibituminous form 8 to 5, and of bituminous from 5 to 0. The terms semianthracite and semibituminous, as used in the trade, are applied to coals with somewhat different ranges of fuel ratio than those used by Frazer. Consequently a somewhat different grouping has come into use, in which anthracite is recognized as having a fuel ratio above 10, semianthracite from 10 to 7, semibituminous from 7 to 3, and bituminous of various kinds, subbituminous and lignite below 3.

The chemical composition of coal is determined in the form of an "ultimate" or elementary analysis. The relative proportions of these elements, or of some of them, can then be used to determine the relations of the various coals. These proportions are usually used in the form of a ratio, or index of classification, such as the ratio of carbon to hydrogen,[c] carbon to oxygen, or some other ratio[d] or

[a] This term, although well enough understood for practical purposes, is somewhat misleading, for analysis implies a separation into constituents, yet the volatile matter as obtained in a "proximate analysis" is not a constituent of the coal, but a product of destructive distillation.

[b] Trans. Am. Inst. Min. Eng., vol. 6, 1877, p. 430; Geol. Survey Pennsylvania, Vol. MM, 1879, pp. 128–144.

[c] Campbell, Marius R., Trans. Am. Inst. Min. Eng., vol. 36, 1906, pp. 324–340; Prof. Paper U. S. Geol. Survey No. 48, pt. 1, 1906, pp 156–173.

[d] Parr, S. W., Illinois Geol. Survey, Bull. 3, 1906, pp. 27–78. Grout, Frank F., Economic Geology, vol. 2, 1907, pp. 225–241.

proportion, involving in some cases more than the elementary composition of the coal. None of these schemes have been elaborated and the exact boundaries defined for the classes of coal here under consideration, nor has it yet been shown that for these kinds of coal they are any improvement over the old fuel ratios. The fact is that any ratio or index of classification is of value only as a convenient index, and that a satisfactory classification must be based upon all the properties of coal and on a knowledge of its genesis.

Variation in character.—The table of analyses on page 84 shows that there is considerable difference in the relative proportion of fixed carbon and volatile matter in coals from the eastern and the western ends of the field; in that from the eastern end the amount of fixed carbon is greater and the volatile matter is less, and hence the fuel ratio is greater. East of Carbon Mountain, and in the northern end of the valley of Canyon Creek, the fuel ratios exceed 11, ranging from 11.42 to 15.88. In the lower end of the valley of Canyon Creek and in the upper end of the valley of Clear Creek, the fuel ratios range from 6.43[a] to 11.12. In the lower part of the valley of Clear Creek, and everywhere west of it, the fuel ratios range from 6.64 to 3.97 or 3.40.[b]

The tables of analyses on pp. 86–87 show somewhat different fuel ratios, ranging in the eastern district from 12.61 to 19.62, in the middle district from 7.22 to 11.12, and in the western district from 3.61 to 7.07. The fuel ratios of both tables thus show that the coal is anthracite in the eastern district, semianthracite in the middle district, and semibituminous in the western district.

The carbon-hydrogen ratios also show quite plainly the differences in the character of the coal of the three districts. These ratios range in the eastern district from 22.81 to 25.10, in the middle district from 19.66 to 23.21, and in the western district from 15.42 to 22.89. There is some overlapping of values, but in general the differences between the three districts are quite plainly shown. These limits do not agree very well with the provisional limits suggested by Campbell[c] of 26 (?) to (?) for anthracite, 23 (?) to 26 (?) for semianthracite, and 20 to 23 (?) for semibituminous. Campbell's grouping of these classes of coal was, however, not based upon a sufficient number of analyses, and he suggested that the limits would probably be changed when more analyses were available.

[a] This sample contains 24 per cent of ash. Consequently, since excessive ash usually appears to lower the fuel ratio, possibly because of the affinity of clay for oily substances, the next lower fuel ratio (7.22) should perhaps be regarded as near the typical lower range of this group of coals.

[b] This sample (No. 65) also contains an excessive amount of ash and consequently has an abnormal fuel ratio.

[c] Campbell, Marius R., The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, 1906, p. 340.

Carbon-oxygen ratios fail utterly to show any unity of character of coal in either district, or any marked difference between the several districts. The highest ratios (54.40 and 33.23) are from coking coals of the western district, and some of the lower ones (9.66 and 14.49) are from coals whose other characters are anthracitic.

The carbon-oxygen ratio is theoretically a good index of classification, but it fails practically for these classes of coals, because incomplete removal of moisture in air drying has an inordinate effect upon the ratio, since moisture is eight-ninths oxygen, and consequently a very little residual moisture can contain more oxygen than the dry coal should. When we have an accurate and standardized method of removing extraneous moisture (and nothing else), then the carbon-oxygen ratio should furnish an excellent index of classification of coal, but at present its use is impractical.

The separation of the coals into three groups (p. 90) on the basis of their fuel ratios is confirmed by the fact that the coals of the eastern group show some of the physical properties (p. 81) and the behavior on burning (p. 82) characteristic of anthracite, while the coals of the western group have the physical properties, flame, and coking properties of semibituminous coal. The coals of the intermediate group are soft, burn with a short smokeless flame, and do not coke, thus agreeing in all their properties with the semianthracites. The limits of these groups, as far as could be determined from the present investigations, are shown on Pl. VIII (pocket), which gives the area and distribution of the anthracite, semianthracite, and semibituminous. Those limits are subject to revision in the light of further knowledge, especially where the lines are drawn through regions from which no samples have been tested. It will doubtless be found that such lines, as far as definite lines of separation exist, are sinuous, and that the area of each group contains outlying areas of the other groups. Within each of the groups as outlined above no regular variation has been noted.

The explanation of this geographic variation is to be found in the relation to the structure. The anthracite occurs in a region of great structural complexity (p. 42), the rocks being very closely folded and much faulted. The coking coal occurs in a region of simpler structure in which the folds are open. The semianthracite occupies a region of intermediate structural type. Distance from the Chugach Mountains also doubtless has played a part in the distribution of the various kinds of coal, especially if there have been intrusions of large and numerous igneous masses subsequent to the deposition of the coal. Local intrusions are more abundant in the anthracite region, but appear not to be either numerous enough or large enough to have been primarily responsible for the regional variation in the

coal. Where such dikes or sills (pp. 70, 71, 72) have come into direct contact with the coal they have driven off the volatile constituents and transformed part of it into a dense natural coke, as shown on Pl. IX, *B*. The effect of such intrusion, as far as could be judged from the instances noted, was extremely local, the coal being altered for only a few inches from the contact.

COMPARISON WITH OTHER COAL.

It was stated above (p. 81) that coal having all the physical characteristics of the best anthracite is known in this region only from float specimens and from outcrops which have not been sampled. The physical properties of these leads to favorable comparison with the best Pennsylvania anthracite. Workable beds of such character have, however, not been opened or sampled, and it is not known whether they exist.

The samples of anthracite, of which analyses and tests are given on pages 84–87, came from beds which do not show all the physical properties of the best anthracite. The analyses and tests also show that this coal is of somewhat lower degree of carbonization than the best Pennsylvania coal. It is, however, as far as chemical and combustion properties are concerned, an excellent fuel.

The semianthracite is of about the same character as the Loyalsock or Bernice basin coal of Pennsylvania.

The semibituminous coal is very close in composition, heating power, and in most of its other properties to the Pocahontas (West Virginia) and Georges Creek (Maryland) coal and to other coals of the Appalachian coal fields.

The fuel and commercial value of these coals as compared with other coals with which they may come in competition are discussed under the heading of markets (pp. 111–112).

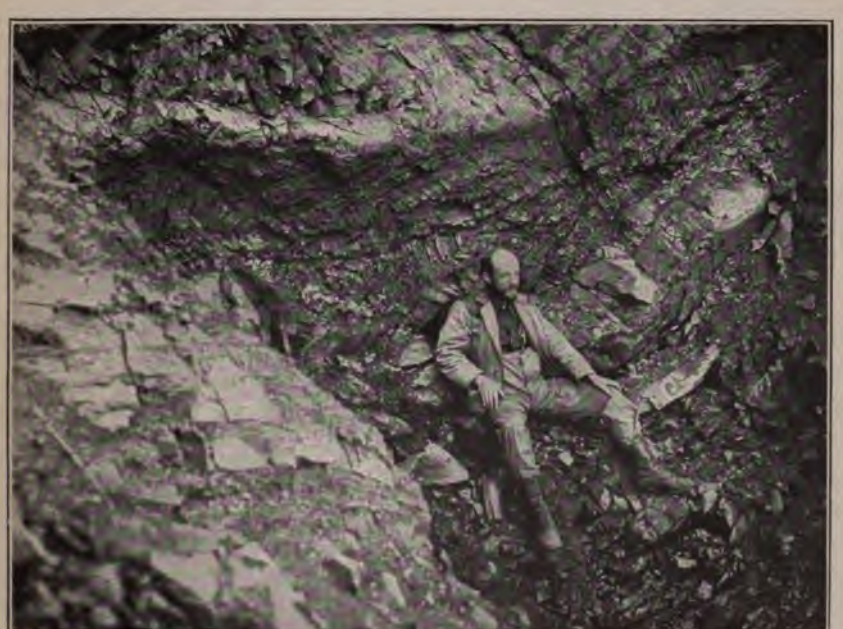
PROSPECTIVE MINING CONDITIONS.

The geologic factors which will affect the cost of mining in this region include the topographic position of the outcrops, the steep dips and complicated structure, the variability in thickness and the possible lack of persistence of the beds, the friable character of the coal, and the occurrence of explosive gases and of large amounts of underground water. These, with the additional questions of title to the land, of cost of labor and supplies, of transportation, and of markets, determine the possibility of profitable mining.

POSITION OF THE COAL.

The coal-bearing rocks occur in regions of considerable relief, and consequently a large amount of the coal is above drainage level. A large number of the coal beds are known to outcrop in the bottoms of

A. VALLEY OF SHEEP CREEK, SHOWING COAL OUTCROPS ON THE MOUNTAIN FACE.



B. NATURAL COKE AND DIABASE SILLS AT THE SOUTH END OF CARBON MOUNTAIN.

the valleys, and the dip is such that all (if persistent for that distance) can be reached by tunnels at the level of the valley floors. There is no doubt that enough coal can be thus reached to support a large mining industry for a long time. Shafting or slope mining will not be necessary for many years, although the later development of the region will doubtless depend on the coal which is below the general drainage level.

ATTITUDE OF THE COAL.[a]

The effect of dip, in addition to that discussed above in regard to the position of the coal beds, is chiefly to determine the method of mining. Steep dips do not make mining impossible or even excessively costly. They introduce no problems which have not already been successfully met in other fields.

The possible overturned folds and the faults introduce problems the scope of which can perhaps be determined only by exploration of the seams in depth. It seems probable that there are areas within the field in which, because of these difficulties, the coal can not be successfully mined. (See fig. 1, p. 42.) These must be determined by careful surface prospecting, followed by either boring or tunneling at critical points. The anthracite field is especially liable to be affected by these difficulties, which, on the one hand, will be compensated for, in part at least, by the greater value of the coal.

PERSISTENCE OF THE COAL.

Variability in thickness of the seams, especially of the thicker ones, may be considered an ever-present problem, the exact magnitude of which can be determined only by underground exploration. It is the current belief in the region that the seams will assume constant thickness and attitudes as soon as they are followed under a heavy cover of overlying rock. Such is not necessarily the case. The swellings and pinchings of the coal do not depend on the nature of the surface of the ground, but on the mode of formation of the coal bed and on the structure of the rocks. Faults or breaks in the coal, pockets, and squeezes are just as liable to be found under the center of a uniform plateau as on the edges of canyons, and must be determined by the position of the rocks in solid outcrop or by boring or tunneling, and not by the character of the surface of the ground. It is certain that these variations will always be a serious problem in mining in this region; but on the other hand, it is likely that they will in large degree be balanced by numerous areas of excessively thick beds and by the high fuel value of the coal.

---

[a] See description of the structure, pp. 42–43.

PHYSICAL CONDITION OF THE COAL.

The friability of the coal, if it persists beyond the zone of surface weathering, will very seriously affect the market value of the anthracite. If the anthracite yields a large proportion of slack, and especially if it crushes during transportation, it will be at a decided disadvantage in the market. No openings on the anthracite have as yet been driven beyond the zone of surface disintegration, so it is impossible to tell whether or not the coal below the surface is sufficiently firm to stand handling. In some of the stream beds are numerous pieces of anthracite which are firm and hard, indicating either that these pieces came from fresh exposures, where the coal was not softened and broken up by frost and other weathering, or that there are beds which are better than those which have been prospected. An opening driven to a sufficient depth on one of the beds would settle this question.

The semibituminous coking coals, although equally friable, are not so seriously affected by this condition, for, as has already been pointed out, such coals will probably be used in part for the manufacture of coke, and when used as steam or other heating coal they will fuse and form a solid mass as soon as put in the furnace.

PRESENCE OF WATER AND GAS.

It is probable that underground water will be encountered in large amounts, owing to the abundance of surface water and the deep fracturing of the rocks. Fortunately, there is a large amount of coal above the general drainage level, so it will not be necessary to resort to shafting for a long time. Consequently the water, although it may be very annoying, will not add materially to the expense of mining.

Gases have been encountered in several of the longer tunnels and will have to be considered as a factor in the cost of mining. It will probably be necessary to resort both to very careful ventilation and to the use of safety lamps. Some legislative provision should be made for this before mining begins.

SHIPMENT.

There is now no available market for Bering River coal and there will be none, except in a limited way for fuel at the local settlements and oil wells, until shipping facilities are provided.

The question of transportation to the several harbors under consideration has already been discussed under railway routes (pp. 23–24). A modification of these proposed methods of shipment has been sug-

gested, which involves transportation of the coal by shallow-draft barges from shoal water to wharves or anchorage on deep, sheltered water. This plan is possible, although it has the disadvantage of interference by the ice during part of the winter.

The cost of shipping coal from whatever harbor is chosen to the places where the coal will be used depends on a readjustment of existing facilities and rates. The existing steamers, although they carry little southbound freight except canned salmon and copper ore, will furnish no adequate facilities for the shipment of the output of a coal mine. When this region produces coal on a commercial scale it must depend for shipment on special coal-carrying vessels. The ocean rates under such conditions will bear no relation to the rates on such commodities as the steamers now carry. Comparison should rather be made with rates on ore and coal on the Great Lakes and on coal on the regular ocean routes.

MARKETS.

The question of markets for Alaska coal is a vital one in connection with the present activity in the developments of coal lands, both in the Bering River field and elsewhere in Alaska. The problem has already been discussed by Brooks [a] and by the writer.[b] The following discussion follows very closely that in the latter paper, but the statistics are brought up to date and the estimates revised.

CONSUMPTION OF FUEL IN ALASKA.

AMOUNT AND SOURCES.

The coal consumption of Alaska from June, 1904, to June, 1905, is estimated at 110,000 tons, derived from the following sources:

Consumption of coal in Alaska, June, 1904, to June, 1905.

	Long tons.
Local supply	[c] 2,440
Imported from United States	[d] 42,728
Imported from foreign countries, chiefly British Columbia	[d] 64,832
	110,000

It is estimated that an additional amount of at least 137,000 tons is consumed by steamers plying between United States or foreign ports

[a] Brooks, Alfred H., The outlook for coal mining in Alaska: Trans. Am. Inst. Min. Eng., vol. 36, 1905, pp. 683–702.

[b] Martin, G. C., Markets for Alaska coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 18–29.

[c] Estimated (the available statistics being for the calendar year).

[d] From table on p. 97.

and Alaska. This fuel comes largely from the home ports of the steamers or chiefly from Puget Sound. The fuel of local coastwise and river boats is, however, included in the total of 110,000 tons. The total coal consumed in Alaska and on voyages thereto is at least 247,000 long tons.

This is not the entire amount of fuel used, for there is a large but unknown amount of wood burned and over 2,700,000 gallons of crude petroleum and 700,000 gallons of naphtha were shipped to Alaska during 1905.

DISPOSAL.

This coal is consumed approximately as follows:

Distribution of coal consumed in Alaska, June, 1904, to June, 1905.

	Long tons.
Towns and mines:	
Southeastern Alaska	[a] 42,000
Pacific coast from Yakutat to Dutch Harbor	[a] 10,000
Bering Sea and Arctic coast	[a] 26,000
Canneries and cannery boats:	
Southeastern Alaska	[a] 5,000
Pacific coast from Yakutat to Chignik	[a] 5,000
Bristol Bay	[a] 12,000
Steamers:	
Local coastwise and river steamers (excluding cannery boats)	[a] 10,000
Puget Sound to southeastern Alaska	[b] 45,000
Puget Sound to Prince William Sound and Cook Inlet	[b] 23,000
Puget Sound to Nome	[b] 32,000
San Francisco to Alaska	[c] 7,000
British Columbia to southeastern Alaska	[c] 25,000
Foreign ports to Nome	[c] 5,000
	247,000

The bulk of the crude petroleum was used in Seward Peninsula and on the Yukon, while the larger part of the naphtha went to the same regions, the remainder being used on the Pacific Coast. Almost all of the crude petroleum and of the naphtha was used for heat and power, the petroleum under boilers and the naphtha in engines.

[a] Estimated from customs reports. The individual items may not be exact, but the total of these items (110,000 tons), as given in the preceding table, is fairly accurate.

[b] From data furnished chiefly by the steamship companies.

[c] Computed from tonnage and horsepower of boats.

PROSPECTIVE INCREASE IN USE OF COAL.

The shipments of coal to Alaska during the last four years are shown in the following table:

Shipments of coal to Alaska, July 1, 1902, to June 30, 1906.[a]

	Twelve months ending June 30—							
	1903.		1904.		1905.		1906.	
	Long tons.	Value.[b]	Long tons.	Value.[b]	Long tons.	Value.[b]	Long tons.	Value.[b]
Domestic anthracite	20	$276	.....	.....	5	$85	.....	.....
Domestic bituminous	56,120	255,841	41,704	$193,740	42,245	187,352	67,293	$265,047
Domestic coke	65	288	392	2,251	478	4,281	346	3,676
Foreign anthracite	.....	.....	.....	.....	10	148	304	1,836
Canadian bituminous	54,072	216,089	63,652	261,987	59,272	260,110	41,481	187,312
Other foreign bituminous	.....	.....	1,909	7,303	.....	.....	.....	.....
Foreign bituminous, shipped via United States	40	350	3,324	23,904	5,550	29,673	706	4,838
Total	110,317	472,844	110,981	489,185	107,580	481,657	110,130	462,709

[a] Commerce of the noncontiguous territory of the United States, Bureau of Statistics, 1903, 1904, 1905, 1906.
[b] At port of shipment.

An increase in the consumption of coal is to be expected from the present rate of development of the region and from the initiation of new enterprises, such as the building of railroads and smelters. These factors of increase will act directly, in the fuel actually consumed by such enterprises, and indirectly in the stimulus to trade and the increase in population which will result. Neither of these direct factors will be large at first. A few small mines along the railroads will supply all the fuel which they will consume, while all the copper ore produced in Alaska in 1906 could be smelted with less than 6,000 tons of coke. These items will, however, probably both increase very rapidly and must be considered very important factors in the development of local industries. Mines situated on the coast or having tide-water connections will probably be able to supply a large part of the bunker coal consumed on both local steamers and those from the United States and foreign ports. This now amounts to 147,000 tons, divided as is shown in the table on page 96.

Mines shipping first-class coal from ports on Controller Bay or Prince William Sound should be able to secure immediately half or possibly all of the patronage of steamers running to Prince William Sound and Cook Inlet, provided the prices are right. A large proportion of the patronage of the other Alaska steamers can probably be secured by shipping the coal either to the Alaska termini of

these lines or to Puget Sound or San Francisco. The aggregate tonnage of Alaska steamers which, according to the reports of the Bureau of Statistics, was increasing at the rate of 6 per cent per annum from 1903 to 1905, increased 17 per cent from 1905 to 1906. A rapid rate of increase may be expected in the future.

COMPETITION WITH PETROLEUM.

The question of the competition between coal and petroleum very seriously affects the possibility of developing an important coal-mining industry in Alaska. The use of petroleum has already, to a large degree, stopped the mining of coal on the Yukon for the river steamers and has driven out part of the imported coal used both there and in other parts of Alaska. It has also, to a large extent, driven the Washington, Oregon, and British Columbia coals from the San Francisco market, thus spoiling what might otherwise be a very important market for Alaska coal.

USE OF PETROLEUM IN ALASKA.

The importation of petroleum and its fuel products into Alaska is shown in the following table:

Shipments of petroleum to Alaska.[a]

Period.	Crude petroleum.			Naphthas.	
	Gallons.	Barrels.	Value.	Gallons.	Value.
Six months ending—					
December, 1902	21,000	500	$390	60,358	$12,186
June, 1903	840,000	20,000	28,000	210,147	33,831
December, 1903	1,008,000	24,000	36,000	84,776	18,054
June, 1904	1,008,400	24,010	35,823	231,658	43,814
December, 1904	1,008,030	24,001	33,603	106,623	23,904
June, 1905	1,780,326	42,389	59,204	499,196	75,187
December, 1905	935,060	22,263	31,864	214,300	34,734
June, 1906	1,428,000	34,002	20,400	361,681	60,214
December, 1906	1,260,100	30,000	18,009	219,297	40,480

[a] Monthly summary of commerce and finance, Bureau of Statistics, 1902–1906.

EFFECT OF CALIFORNIA PETROLEUM ON PACIFIC COAST COAL TRADE.

It is believed by many that the coal industry on the Pacific coast will not be able to survive this competition, but that California petroleum, because of its lower cost, will ultimately displace coal in all uses to which petroleum is applicable. The statistics contained in the following table will shed some light on this subject:

Relation of production of petroleum to output and price of coal on the Pacific coast.

Year.	Production of petroleum in California (barrels).[a]	Production of coal on the Pacific coast (short tons.)							
		California.[b]		Oregon.[c]		Washington.[d]		Vancouver Island.[e]	Total Pacific coast production.[f]
		Amount.	Price per ton.	Amount.	Price per ton.	Amount.	Price per ton.	Amount.	Amount.
1895	1,208,482	75,453	$2.33	73,685	$3.36	1,191,410	$2.16	1,058,045	2,398,595
1896	1,252,777	78,544	2.12	101,721	2.90	1,195,504	2.00	1,003,769	2,379,538
1897	1,903,411	85,992	2.34	107,289	2.72	1,434,112	1.94	1,019,390	2,646,693
1898	2,257,207	144,288	2.43	58,184	3.65	1,884,517	1.78	1,263,154	3,350,142
1899	2,642,095	160,615	2.67	86,888	3.00	2,029,881	1.78	1,347,583	3,625,059
1900	4,324,484	171,708	3.05	58,864	3.74	2,474,093	1.90	1,549,379	4,254,044
1901	8,786,330	151,079	2.60	69,011	2.51	2,578,217	1.62	1,469,666	4,267,973
1902	13,984,268	84,984	2.99	65,648	2.44	2,681,214	1.72	1,397,385	4,229,231
1903	24,382,472	104,673	2.82	91,144	2.42	3,193,273	1.69	964,068	4,353,158
1904	29,649,434	78,888	4.76	111,540	2.18	3,137,681	1.63	1,145,887	4,473,996
1905	33,427,473	77,050	4.97	109,641	2.58	1,864,926	1.79	1,113,519	4,165,136
1906	33,098,598	25,290	2.40	79,731	2.66	3,276,184	1.80	1,339,383	4,720,588

[a] Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 831.
[b] Idem for 1905 (1906), pp. 554–556; for 1906 (1907), pp. 653–654.
[c] Idem for 1905 (1906), pp. 651–652; for 1906 (1907), pp. 707–708.
[d] Idem for 1905 (1906), pp. 689–691; for 1906 (1907), pp. 733–736.
[e] Ann. Repts. Minister of Mines, British Columbia.
[f] Computed from the other items in this table.

NOTE.—The price of coal per ton as given above represents "spot value" at the mines.

Variation in amount of coal produced and used on the Pacific coast (short tons).

Year.	Total Pacific coast production.[a]	Shipments of coal to the Pacific coast.[b]	Coal consumed on Pacific coast.[a]	Coal consumed in California.[b]	Coal consumed on Pacific coast outside California.[a]
1895	2,398,595	510,120	2,908,715	1,653,520	1,255,195
1896	2,379,538	458,727	2,838,267	1,505,660	1,332,607
1897	2,646,693	421,638	3,068,331	1,601,540	1,466,791
1898	3,350,142	346,222	3,696,364	1,802,373	1,893,991
1899	3,625,059	299,947	3,925,006	1,740,027	2,184,979
1900	4,254,044	292,654	4,546,698	1,889,128	2,657,570
1901	4,267,973	306,746	4,574,719	1,834,785	2,739,934
1902	4,229,231	368,062	4,597,293	1,445,598	3,151,695
1903	4,353,158	456,742	4,809,900	1,215,554	3,594,346
1904	4,473,996	298,039	4,772,035	1,051,072	3,720,963

[a] Computed from the other items in these tables.
[b] The production of coal in 1904 (advance chapter from Mineral Resources U. S. for 1904), U. S. Geol. Survey, 1905, p. 102.

During the ten years (1895 to 1904) completely covered by these tables there has been an extraordinary increase in the output of California petroleum. The production in 1904 (29,649,434 barrels) is 24½ times the amount produced in 1895 (1,208,482 barrels). As this was nearly all fuel oil it might be expected that it would displace a large amount of coal and that we would find, throughout the same period, a corresponding decrease in coal mining and coal trade not only in California but in the other regions which supply California with coal. The statistics, however, show that the production of coal in California increased from 1895 to 1900 and has fluctuated, but on

the whole fallen off, since that time. The production in Oregon has shown an irregular but quite general increase during this ten-year period. The Washington mines have increased their product to almost triple. Vancouver Island mines had a not much greater output at the end of the period than at its beginning, but showed a rise and subsequent fall during the interval. Shipments from Atlantic and oriental ports have decreased somewhat irregularly but very decidedly during these ten years. The amount of coal consumed in California has varied irregularly, but has on the whole shown a decided decrease. The amount of coal consumed on the whole Pacific coast (north of Mexico) has increased from 2,908,715 tons in 1895 to 4,681,012 tons in 1904. The increase on the Pacific coast outside of California is even more striking, the amount having risen from 1,255,195 tons in 1895 to 3,629,940 tons in 1904.

The price of coal mined in California increased during the period under discussion, but subsequently fell (1906). Oregon and Washington coals decreased in value, although the price has been rising from 1904 to 1906. No figures are at hand regarding the prices of Vancouver Island or other imported coals.

The general effect of the increase in petroleum has been to demoralize the San Francisco coal market. The gradual increase in oil output from 1895 to 1900 was accompanied by a very prosperous condition of the coal trade not only in California but throughout the country. After this the output of oil became so great as to preclude all possibility of competition by coal in the oil territory except for those special uses to which oil can not be applied. That is, coal was forced to seek markets of its own, which include, in addition to the special ones mentioned above, those districts in which the relative freight charges on coal and oil make competition possible. In the former the price of coal rose and the demand increased. This result may be attributed to the very factor which in other respects demoralized coal trade. The increase in petroleum output, furnishing a cheap and abundant fuel, stimulated general industrial conditions and thus increased the demand for coal in its special markets.

The cutting down of shipments from the other Pacific coast fields to San Francisco has resulted in a reduction in prices, caused by the attempt to compete with the cheaper petroleum and by the lively competition of the coal mines among themselves in attempting to develop and control new markets nearer home. They have been successful in their home markets, as may be seen by the great increase (289 per cent) in consumption of coal on the northern Pacific coast during the ten years from 1895 to 1904. This means a large increase in manufacturing and other business interests, and indicates that there is a substantial permanent increase in the demand for coal, which helped cause the lately increased price and production and which, barring

overproduction or an unlooked-for invasion of petroleum, should lead to a continuation of the upward tendency in prices.

CAPABILITY OF COAL TO COMPETE WITH PETROLEUM.

The following factors determine the possibility and result of competition between coal and oil:

1. Relative adaptability of coal and oil to the special use under consideration.
2. Relative efficiency of oil and coal.
3. Relative prices as determined by cost of production and freight.
4. Supply available.

Relative adaptability.—The factor of relative adaptability determines the special markets for coal and for oil. In each of these markets the other fuel can not compete at any price. The Bering River coal, like some of the other Alaska coal, is of such quality that it is especially suitable for use as a domestic fuel. As such it should find a widespread market along the Pacific coast, selling at a high price in San Francisco and the California oil fields. Competition with oil will be slight, at least until improvements are made in the methods of burning oil. Competition with other coals will be considered in another place (pp. 106–112).

The coal from the western end of the Bering River field will produce a good quality of coke and, for this purpose, the coal will not come into competition with petroleum, but should sell independent of the presence and cost of oil, the price being determined solely by competition with other coking coals. The present increase in steel and smelter industries will make great demand for such coals.

The Bering River field will also furnish a high-grade blacksmith coal. Petroleum will not compete for this purpose. In fact, the oil fields of the Pacific coast will themselves constitute one of the most attractive markets, and any extension of the oil fields will create new demand for blacksmith coal. The present supply of such coal on the Pacific coast is practically all brought from the east at great cost.

It does not seem practicable at present to adapt petroleum to general naval use. Petroleum will consequently not compete with Alaska coal in this market. Much of the Bering River coal is of such quality as to make it especially suitable for use on warships or wherever a high-grade smokeless steaming coal is required. The only effect which petroleum has at present in this market is to render other coal available for competition and thus indirectly to reduce the selling price. If naval architects succeed in solving the structural and storage problems which at present keep petroleum from being used in this way, present conditions will be changed, for petroleum has many advantages over coal for this use.

Relative efficiency of coal and oil.—The factor of relative efficiency is determined primarily by the quality of the coal, the fuel value of petroleum being more nearly constant.

The United States Naval "Liquid Fuel" Board has obtained the following results from tests with the Hohenstein marine water-tube boiler:

Equivalent evaporation from and at 212° F. per pound of oil.[a]

	Pounds.
Beaumont petroleum (average of 47 tests)	12.51
California petroleum (average of 20 tests)	11.57
Mixture (dregs) of Beaumont and California petroleum (average of 2 tests)	11.52

Equivalent evaporation from and at 212° F. per pound of coal as fired.[b]

	Pounds.
Pocahontas coal, run of mine (average of tests 1 to 3)	8.65
Pocahontas coal, run of mine (average of tests 4 to 6)	9.40
New River coal, run of mine (average of tests 7 to 9)	9.37
Pocahontas coal, hand picked and screened (average of tests 10 to 17)	9.30

From each can or bag of coal that was brought into the fireroom a specimen was taken and collected in a box, so that there could be forwarded for analysis a fair sample of the fuel used.

The following table gives the result of the analyses of samples of each lot of coal. The analyses were made by the chemist at the New York Navy-Yard:[c]

Analyses of coal used in comparative fuel tests.

	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
Pocahontas coal, run of mine, used in tests 1 to 3	0.49	17.61	73.30	8.60	0.48	4.16
Pocahontas coal, run of mine, used in tests 4 to 6	.79	19.53	75.78	3.90	.71	3.88
New River coal, run of mine, used in tests 7 to 9	.49	21.79	72.99	4.73	.46	3.35
Pocahontas coal, hand picked and screened, used in tests 10 to 17	.73	19.62	76.81	2.84	.73	3.91

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	B. t. u.
Pocahontas coal, run of mine, used in tests 1 to 3	28.26	3.89	4.12	0.64	0.49	8.60	14,067
Pocahontas coal, run of mine, used in tests 4 to 6	84.96	4.07	5.46	.90	.71	3.90	14,534
New River coal, run of mine, used in tests 7 to 9	83.60	4.85	4.87	1.41	.46	4.81	14,841
Pocahontas coal, hand picked and screened, used in tests 10 to 17	85.94	4.45	4.50	1.14	.82	3.15	14,992

[a] Rept. U. S. Naval "Liquid Fuel" Board, 1904, pp. 250–252.

[b] Op. cit., p. 52.

[c] Op. cit., p. 10.

The following conclusions are stated in the report:[a]

The relative evaporative efficiency of oil and coal as a fuel, as determined by this extended series of comparative experiments, is practically in the proportion of 15 to 10. The actual superiority of oil will be considerably greater, for in the coal experiments unusual skill was exercised in the management of the fires. Lump coal of superior quality was used; and as the tests with coal were of comparatively short duration, the resulting loss from cleaning fires was much less than would occur in actual service. The oil experiments, however, were carried on under conditions that more closely approximated those that could be secured on board the sea-going vessel. The actual evaporative efficiency of a pound of oil as compared with a pound of coal will therefore be in the ratio of 17 to 10, and these figures can be regarded as substantially correct.

* * * * * * *

In noting the comparative economical efficiency, for naval purposes, of oil and coal, there must also be taken into consideration the fact that a ton of oil can be stowed in somewhat less space than a ton of bituminous coal. Then, again, it must be considered that in the carrying of the oil the compartments can be more completely filled. The relative efficiency of oil and good steaming coal from the naval standpoint of fuel supply in war ships may thus be regarded as in the ratio of 18 to 10.

It was found by comparative tests of coal and oil on the steamship *Alameda* between San Francisco and Honolulu that the efficiency of equal weights of oil fuel and a mixture of British Columbia and Australia coal was in the ratio of 1.42 to 1, or that 1 ton of coal equaled 4.10 barrels of oil.

The following quotations will show the relative values of various coals in comparison with petroleum:

Tests have proved that 1 pound of California petroleum used on a passenger locomotive evaporated 10.96 pounds of water from and at 212° F., as compared with 7.14 pounds of water under like conditions evaporated by 1 pound of Comox bituminous coal, or 4 barrels of oil did the work of 1 ton of coal. This is rather below the results attained by other tests, which in many cases showed that from 3¼ to 3½ barrels of petroleum did the work of 1 ton of coal.[b]

Comparison of petroleum with various coals.[c]

Combustible.	Pounds of water evaporated at 212° F. per pound of combustible.	Barrels of petroleum required to do the same amount of evaporation as 1 ton of coal.	Cost of coal per ton to equal petroleum at $1 per barrel.	Less 10 per cent, owing to the greater economy in handling petroleum.
Petroleum, 15° to 18° Baumé	16.0	.....	.....	.....
Cardiff lump, Wales	10.0	4.0	$4.00	$3.60
Cape Breton, Canada	9.2	3.7	3.70	3.33
Nanaimo, British Columbia	7.3	2.9	2.90	2.61
Cooperative, British Columbia	8.9	3.6	3.60	3.24
Greta, Washington	7.6	3.0	3.00	2.70
Carbon Hill, Washington	7.6	3.0	3.00	2.70

[a] Op. cit., pp. 417–418.

[b] Oliphant, F. H., The production of petroleum in 1901: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 583.

[c] Oliphant, F. H., The production of petroleum in 1903 (separate from Mineral Resources U. S. for 1903), U. S. Geol. Survey, 1904, p. 170.

The following estimates have been gathered from various sources:

Equivalent in petroleum of 1 ton of various coals.

	Barrels of petroleum.
Pocahontas coal	4.5
Georges Creek coal	4.3
Pittsburg coal	4.3
Nanaimo coal	3.2
Carbon Hill coal	2.7

There is some variation in the values given. This may be ascribed in part to differences in quality between different parts of the same field, in part to differences in the efficiency of the boilers, in part to differences in value of various petroleums, and in part to errors.

There is, however, no doubt that a large part of the Bering River coal is of such high grade that a ton of it will equal at least 4 barrels and probably 4.5 or more barrels of California oil.

These figures are all based on the relative efficiency of coal and petroleum when used with a steam engine. The values representing the relative efficiency of these fuels when used with a gas engine,[a] or for direct heat (as in roasting or smelting, or in a stove), might be very different.

Relative prices.—It is impossible to here make any definite estimate of the cost of producing and shipping Alaska coal. It would seem, however, that it should not be much in excess of the cost in many other western mining districts. It is reasonable to assume that with proper management it could be reduced below the present selling price on Vancouver Island.

Freight rates from Bering River mines to tide water ought not to be excessive, and ocean rates from Alaska to Puget Sound or San Francisco should be very low.

The price of California crude petroleum at the wells ranged in 1904 from 17½ cents to $2 per barrel, depending both on local and temporary differences in supply and demand and on differences in quality. The average price was about 28 cents per barrel, as compared with 30 cents in 1903. The cost per barrel, delivered at San Francisco, was from $1.40 to $1.50 in 1904.

These prices in equivalents of Puget Sound coal, estimating 1 ton of coal as equal to 3 barrels of oil, are as follows:

Petroleum at $0.125 per barrel = coal at $0.375 per ton.
Petroleum at $0.28 per barrel = coal at $0.84 per ton.
Petroleum at $1.40 per barrel = coal at $4.20 per ton.
Petroleum at $1.50 per barrel = coal at $4.50 per ton.

The coal values will be about 25 to 33 per cent greater for the best Bering River coal. They show that it is impossible for any coal to

[a] See preliminary report on the operations of the coal-testing plant, etc.: Bull. U. S. *Geol. Survey* No. 261, 1905, pp. 16, 17, 85-120.

compete with fuel oil in those districts where oil has the advantage of transportation rates. It is possible, however, that rates to San Francisco might be made such that coal and oil can compete. There ought to be lively competition north of San Francisco if the cost of mining and shipment of coal is reduced to a minimum.

Available supply.—It is not likely that either petroleum or coal could be produced on the Pacific coast in sufficient amount to supplant the other without soon proving inadequate to the demand, in which case there would be an advance in price and consequent reopening of competition.

The following conclusions [a] are of interest on this point:

Careful consideration has been given the question as to the supply of crude petroleum in the United States available for fuel purposes. This matter has been specially investigated by Prof. Arthur L. Williston, of the Pratt Institute, Brooklyn, N. Y., who reports as follows:

"The supply of oil which is available for fuel in the United States, therefore, is, first, the small percentage (probably not over 2 or 3 per cent) of the total production of the Pennsylvania and Ohio oil—the residuum from the process of refining; second, crude oil from the Ohio and Indiana fields, wherever the price of coal makes the burning of oil at 95 cents or $1 per barrel (plus freight) profitable; third, those portions of the California oil which are not best suited for refining; fourth, practically the entire output of the Texas field."

The demands for the better grades of oil for refining purposes will probably keep pace with its production; consequently we can never expect to see such grades of oil compete with coal to any large extent.

On the other hand, the refining value of the Texas oil and much of the California oil is so low that its value will probably always be largely controlled by the demand for it for fuel purposes. It is inconceivable that a fuel which has so many distinct advantages, and which is not unlimited in its supply, should sell in all markets at a price which would make it cheaper to burn than coal. Any great demand for such a fuel would bring its price up at once.

On the other hand, so long as there is an assured supply of Texas and California fuel oil, the price of such oil that has little intrinsic value for refining, will probably remain low enough to enable it to compete successfully with coal in those regions where coal is scarce in quantity and poor in quality. And the area in which this condition exists is sufficiently wide to create a demand for the fuel oil that will soon equal the supply, unless further stores of oil are found as the demand for it increases.

The fact should be remembered that in every region there is with each succeeding year a progressive proportionate increase in the percentage of the yield consumed for illuminating purposes.

The petroleum output of California in 1904, which was more than one-fourth (25.33 per cent) of the production of the United States and over 12 per cent of the entire production of the world, is the

[a] Rept. U. S. Naval "Liquid Fuel" Board, 1904, p. 416.

equivalent of only 1.7 or 1.8 times the coal then burned on the Pacific coast of North America alone. In 1906 the consumption of fuel oil in California exceeded the production in that State.[a] It would appear from this that the supply of fuel petroleum must increase very much before it will be possible for petroleum to make much greater inroads into the coal market without ultimately causing a reactionary advance in prices. Such an increase from the present producing oil fields is not probable.

COMPETITION WITH OTHER COAL.

ALASKA COAL.

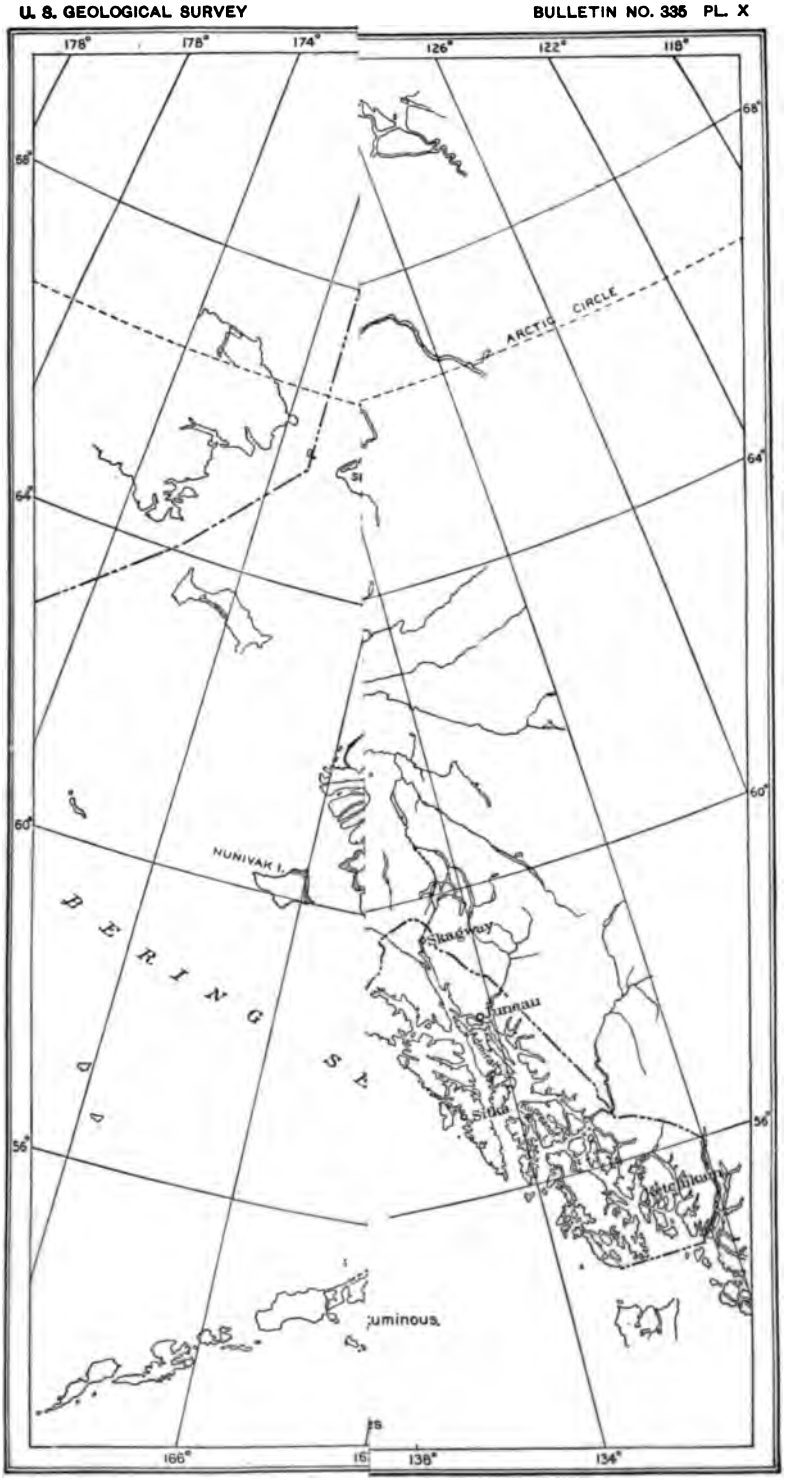
There are many districts in various parts of Alaska which may produce coal either for local use or for shipment. It is important to consider all of these because, while only those which possess coal of the best quality could compete with Bering River coal in outside markets, most of them must be regarded as possible sources of local supply, and may thus restrict the market which the better coal can reach.

The writer has recently published a brief summary[b] of existing knowledge of Alaska coal, which has been extensively drawn upon in the preparation of the following pages.

Distribution and area.—The distribution of the coal fields of Alaska is indicated on the map (Pl. X), which shows (1) known areas of workable thickness of high-grade coal (anthracite and semi-bituminous); (2) known areas of workable thicknesses of lower-grade coal (bituminous and subbituminous); (3) known areas of workable lignites, and (4) areas of coal-bearing rocks. The last includes those areas which are known to contain some coal but in which beds thick enough to be mined have not yet been discovered, areas in which coal has been authentically reported, but concerning which detailed information is lacking, and areas in which the character of the rocks is similar to that in neighboring coal fields and where, consequently, the occurrence of coal is to be expected. These statements apply also to the table of areas given on p. 107. The areas mapped as "coal-bearing rocks" are consequently not well defined and must be regarded as subject to considerable changes by subsequent exploration. They are intended to indicate the regions in which new discoveries of coal seem, in the light of our present knowledge, to be most probable. The extent of the various areas noted above, as well as the area of each individual coal field, is shown in the following table, which gives a total of at least 1,238 square miles,

[a] Griswold, W. T., Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 827.

[b] Martin, G. C., The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 40-46.


178°
178°
174°
126°
122°
118°
68°
68°
ARCTIC CIRCLE
64°
64°
60°
60°
NUNIVAK I.
BERING SEA
Juneau
Sitka
56°
56°
166°
138°
134°

MAP ; KNOWN.

or 792,320 acres, of known workable coal, and 12,576 square miles, or 8,048,640 acres, of "coal-bearing rocks:"

Areas[a] of Alaska coal fields.

[Square miles.]

	Coal areas.	Areas[b] of coal-bearing rocks.
Anthracite:		
Bering River	26.4	
Matanuska River	4.2	
	30.6	
Semibituminous:		
Bering River	20.2	620
Matanuska River	20.3	
Cape Lisburne	14.2	
	54.7	
Bituminous:		
Matanuska River	22.0	900
Alaska Peninsula	69.0	657
Yukon Basin	167.0	2,490
Cape Lisburne	205.0	1,255
Anaktuvuk River	9.0	68
	472.0	5,370
Total anthracite and bituminous	557.3	5,990
Lignite:		
Southeastern Alaska	10.0	50
Cook Inlet region	304.0	2,565
Southwestern Alaska	16.0	300
Copper River		20
Yukon Basin	216.0	1,557
Bering Sea	52.0	426
Northern Alaska	83.0	1,736
	681.0	6,654
Grand total	1,238.0	12,576

[a] The difference between the areas given here and those which have been published elsewhere is due chiefly to the recognition of four classes of coal instead of three, and the consequent division of the Lisburne areas into semibituminous and bituminous and of the Yukon areas into bituminous and lignite, and of similar changes in other smaller areas.
[b] See explanation on p. 106.

Pacific coast region.—The Pacific coast coal fields (which include the Bering River field) are of moderate area but of wide distribution. They include both Mesozoic and Tertiary coals, having a complete range in composition from a good quality of anthracite, through high-grade semibituminous steam and coking coals and ordinary bituminous coal, to lignites of various character. The coal beds are frequently of great thickness, especially where the coal is of high carbonization, but unfortunately there usually goes with the high grade of coal and great thickness of bed an irregularity of geologic structure unfavorable to mining conditions. The Pacific coast coals are in general favorably situated for shipment, and in this respect,

as in their character, offer possibilities for a larger, more regular, and wider market than any of the other Alaska coals.

Interior region.—The interior region, which is here defined to include the valleys of Copper and Yukon rivers and their tributaries, contains Cretaceous bituminous coal on the lower Yukon and Tertiary lignite and subbituminous coal on the upper Yukon and in the Tanana, Koyukuk, and Copper river basins. None of this coal is suitable for export, but it may be of considerable importance as local fuel.

Bering Sea and Arctic slope.—The coal of this region has great range in geologic age and great variety in character. Coal is present in the Carboniferous, Jurassic, Cretaceous, and Tertiary. In the Cape Lisburne region Carboniferous semibituminous and Jurassic bituminous coals occur, and in the Colville basin Cretaceous bituminous coal and Tertiary lignite are present. In other regions (except at Wainwright Inlet, where the coal is Jurassic), the coal, so far as is now known, is of Tertiary age and is lignite.

It is not likely that any of this coal is of immediate value for other than local use. The high-grade coal at Cape Lisburne may find an extensive market at Nome, but the shipping problems are serious. The other coal is of such character that its market must be restricted to local regions, in which the cost of better imported coal is high. It may be of extreme importance and of great value in local operations, but it is not good enough to ship very far from the mines.

Developments and production.—The coal-mining industry of Alaska is still in a practically undeveloped condition. Coal has been mined intermittently and on a small scale at several places for many years, but the industry has never been of much importance, the maximum total production of all Alaska in any one year being less than 7,000 tons. This has been because the better coal has not been well known until recently and can not be shipped without railway connections from the mines to tide water, and also because no adequate provision has been made for granting title to sufficient tracts to assure profits on the large investments which are required.

The most active mining operations have been on Cook Inlet, on the Alaska Peninsula, on the Yukon, in Seward Peninsula, and at Cape Lisburne. All of these were carried on to obtain local fuel on small coastwise or river steamers, at mining camps, and at canneries.

The most important developments which are now going on outside the Bering River region are preparatory to mining the high-grade Matanuska coal on a large scale for shipment away from the coal fields. This coal, much of which rivals the Bering River coal in amount and quality, is adapted to use[a] on ocean steamers and rail-

[a] *Martin, G. C.*, A reconnaissance of the Matanuska coal field, Alaska, in 1905: Bull. *U. S. Geol. Survey* No. 289, 1906, 36 pp.

ways and for the manufacture of coke, and for other purposes for which high-grade coal is required. Before this coal can be mined it will be necessary to build about 150 miles of railroad.[a] It is believed that this project is legitimate and that if favorable title can be obtained the field will be producing on a large scale within a few years. A railroad is now under construction.

The coal of the interior and northern parts of Alaska will probably be dependent for its market on local demand as long as better coal is being mined in other regions—that is, it can now be sold only where excessive freight rates on outside coals give it the advantage. This local demand will depend chiefly on mining camps and will be transient or permanent, according to whether the mining camps are placer or lode. Such coal fields of the interior as may be on the line of railroads or near lode mines, especially if the ores are smelting ores and the coal capable of coking, will attain considerable importance, but these conditions are contingent on future discoveries and developments, which can not be foretold.

Character of Alaska coal.—The character of the coal in the Alaska coal fields has been stated in the previously published descriptions of the various fields and has been referred to in the preceding pages. A detailed discussion of this subject is consequently not necessary here. The following table is a summary of all the analyses of Alaska coal which have been made for the United States Geological Survey, and will show approximately the character and comparative value of the coal from the various known areas.

Analyses of Alaska coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
ANTHRACITE.						
1. Bering River, average of 7 analyses	7.88	6.15	78.23	7.74	1.30	12.86
2. Matanuska River, 1 sample	2.55	7.08	84.32	6.05	.57	11.90
SEMIANTHRACITE.						
3. Bering River, average of 11 analyses	5.80	8.87	76.06	9.27	1.08	8.77
SEMIBITUMINOUS.						
4. Bering River, coking coal, average of 28 analyses	4.18	14.00	72.42	9.39	1.73	5.28
5. Cape Lisburne, average of 3 analyses	3.66	17.47	75.95	2.92	.96	4.46
6. Matanuska River, coking coal, average of 16 analyses	2.71	20.23	65.39	11.60	.57	3.23
BITUMINOUS.						
7. Lower Yukon, average of 11 analyses	4.68	31.14	56.62	7.56	.48	1.90
SUBBITUMINOUS.						
8. Matanuska River, average of 4 analyses	6.56	35.43	49.44	8.57	.37	1.40
9. Koyukuk River, 1 sample	4.47	34.32	48.26	12.95	.....	1.40
10. Nation River, 1 sample	1.39	40.02	55.55	3.04	2.98	1.39
11. Alaska Peninsula, average of 5 analyses	2.34	38.68	49.75	9.22	1.07	1.30
12. Cape Lisburne, average of 11 analyses	9.35	38.01	47.19	5.45	.35	1.24
13. Anaktuvuk River, 1 sample	6.85	36.39	43.38	13.38	.54	1.20

[a] Brooks, Alfred H., Railway routes, Bull. U. S. Geol. Survey No. 284, 1906, pp. 10–17; Railway routes in Alaska, Nat. Geog. Mag., 1907, pp. 165–190.

Analyses of Alaska coals—Continued.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
LIGNITE.						
14. Port Graham, 1 sample	16.87	37.48	39.12	6.53	.39	1.04
15. Southeastern Alaska, average of 5 samples	1.97	37.84	35.18	24.23	.57	1.02
16. Wainwright Inlet, 1 sample	10.65	42.99	42.94	3.42	.62	1.00
17. Colville River, 1 sample	11.50	30.33	30.27	27.90	.50	1.00
18. Upper Yukon, Canadian, average of 13 analyses	13.08	39.88	39.28	7.72	1.26	.99
19. Upper Yukon, Circle province, average of 3 analyses	10.45	41.81	40.49	7.27	1.30	.97
20. Upper Yukon, Rampart province, average of 6 analyses	11.42	41.15	36.95	10.48	.33	.91
21. Seward Peninsula, 1 sample	24.92	38.15	33.58	3.35	.68	.88
22. Chitistone River, 1 sample	1.65	51.50	40.75	6.10	.....	.79
23. Kachemak Bay, average of 6 analyses	19.85	40.48	30.99	8.68	.35	.77
24. Nenana[a] River, 1 sample	13.02	48.81	32.40	5.77	.16	.66
25. Kodiak Island, 1 sample	12.31	51.48	33.80	2.41	.17	.66
26. Unga Island, average of 2 analyses	10.92	53.36	28.25	7.47	1.36	.62
27. Tyonek, average of 4 analyses	8.35	54.20	30.92	6.53	.38	.58
28. Chistochina River, 1 sample	15.91	60.35	19.46	4.28	.....	.32

[a] Formerly Cantwell River.

1. This report, p. 84.
2. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analysis 1.
3. This report, p. 84.
4. This report, p. 84.
5. Bull. U. S. Geol. Survey No. 278, 1906, p. 47, analyses 13 to 15.
6. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analyses 2 to 17.
7. Bull. U. S. Geol. Survey No. 218, 1903, pp. 62, 63, analyses 26, 28 to 38.
8. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analyses 18 to 21.
9. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analysis 28.
10. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analysis 17.
11. Bull. U. S. Geol. Survey No. 284, 1906, p. 27.
12. Bull. U. S. Geol. Survey No. 278, 1906, p. 47, analyses 1 to 7, 9 to 12.
13. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 607.
14. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
15. Bull. U. S. Geol. Survey No. 284, 1906, p. 27.
16. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 653.
17. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 620.
18. Bull. U. S. Geol. Survey No. 218, 1903, pp. 61, 62, analyses 3 to 15.
19. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analyses 16, 18, 19.
20. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analyses 20 to 25.
21. Bull. U. S. Geol. Survey No. 247, 1905, p. 67.
22. Prof. Paper U. S. Geol. Survey No. 41, 1906, p. 125.
23. Bull. U. S. Geol. Survey No. 259, 1905, p. 170, analyses 3, 4, 7 to 10.
24. Bull. U. S. Geol. Survey No. 218, 1903, p. 62.
25. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
26. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
27. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 23, analyses 1 to 4.
28. Prof. Paper U. S. Geol. Survey No. 41, 1906, p. 124.

IMPORTED COAL.

The coal which is now being shipped to Alaska is derived from the following sources: Vancouver Island, Puget Sound, Australia, the Appalachian region, and Wales. Alaska coal will not only have to compete with these at home, but if it seeks a more extended market will also meet these coals on Puget Sound, at San Francisco, and in the navy-yards and coaling stations of the Pacific, and will also compete to some extent with the coal now being mined in California and Oregon. It is consequently important to compare the character of the Alaska coals with that of all those with which they may come into competition. This may be done by inspecting the following tables of analyses, which are the best available substitutes for actual prac-

tical tests and which may be relied on to give a close approximation to the quality and value of the coal:

Average composition of Pacific coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
British Columbia, Crows Nest Pass, average of 10 analyses [a b]	1.09	21.07	70.54	7.29	0.37	3.35
British Columbia, Comox, average of 9 analyses [b c d]	1.18	28.41	62.91	7.49	1.54	2.21
British Columbia, Nanaimo, average of 6 analyses [b c e]	2.12	34.07	55.94	7.93	.64	1.64
Washington, Wilkeson, average of 7 analyses [f g h]	.92	27.15	61.82	10.11	1.42	2.28
Washington, Cokedale, average of 3 analyses [f h]	1.27	28.04	62.30	8.39	.34	2.22
Washington, Blue Canyon, average of 3 analyses [f g i]	1.62	32.63	60.47	5.28	.53	1.85
Washington, Carbonado, average of 15 analyses [g i]	1.67	33.11	56.74	8.48	.94	1.71
Washington, Roslyn, average of 9 analyses [b f g h i]	2.68	34.37	52.75	9.87	.24	1.53
Washington, Franklin, average of 5 analyses [f g]	3.22	35.40	53.82	7.55	.15	1.52
Washington, Renton, average of 10 analyses [g h]	4.48	36.01	51.17	8.23	.61	1.42
Washington, Newcastle, average of 5 analyses [f g]	7.51	37.69	48.94	5.86	.48	1.30
Washington, Black Diamond, average of 4 analyses [f h]	4.44	40.50	51.73	3.33	.44	1.28
Oregon, Coos Bay, average of 4 analyses [f]	10.41	46.15	36.85	6.59	1.02	.80
California, average of 10 analyses [j]	11.32	45.09	35.91	7.68	.....	.80
Japan, average of 8 analyses [k]	2.62	42.49	50.07	4.82	.92	1.18
Philippines (Cebu) average of 9 analyses [l]	14.00	31.08	50.53	4.85	.....	1.64
Philippines (Batan), average of 5 analyses [l]	13.57	36.91	44.92	4.60	.....	1.22
New South Wales, southern, average of 21 analyses [m]	.97	23.10	56.26	10.67	.46	2.83
New South Wales, western, average of 13 analyses [m]	1.87	31.49	52.61	14.03	.63	1.67
New South Wales, northern, average of 77 analyses [m]	1.92	35.09	54.08	8.91	.54	1.62

[a] Ann. Rept. Geol. Survey Canada, Vol. 3, pt. 2, 1887–8, pp. 12T–15T.
[b] Ann. Rept. Minister of Mines, British Columbia, for 1902, p. 262H.
[c] Ann. Rept. Geol. Survey Canada, 1872–3, pp. 76–78.
[d] Ann. Rept. Geol. Survey Canada, 1876–7, p. 468.
[e] Ann. Rept. Geol. Survey Canada, 1882–1884, p. 37M.
[f] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 490, 501, 510.
[g] Ann. Rept. Washington Geol. Survey, Vol. 2, 1902, p. 270.
[h] Rept. State Inspector of Mines, Washington, 1901–2.
[i] Ann. Rept. Washington Geol. Survey, Vol. 1, 1901, Pls. XXV, XXVII.
[j] Geology of California, Vol. 3, p. 48.
[k] Outlines of the geology of Japan, Imperial Geol. Survey of Japan, 1902, p. 190.
[l] The coal measures of the Philippines (report to the United States military governor in the Philippines), War Department, 1901, pp. 178–181, 256–259.
[m] Mineral resources of New South Wales, 1901, pp. 324–348.

Average composition of eastern coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.	Remarks.
Pennsylvania, anthracite, average of 9 analyses. [a]	3.39	3.81	83.79	8.42	0.59	22.33	Domestic coal.
Loyalsock, Pa., semianthracite, average of 4 analyses. [a]	1.49	11.07	78.88	7.69	.86	7.13	Do.
Pocahontas, W. Va., semibituminous, average of 38 analyses. [b]	.73	17.43	77.71	4.63	.62	4.46	Steam and coking coal.
Georges Creek, Md., semibituminous, average of 53 analyses. [c]	.70	18.81	72.96	7.26	1.01	3.89	Steam coal.
Connellsville, Pa., bituminous, average of 3 analyses. [d]	1.07	32.70	60.28	5.95	.81	1.84	Coking coal.
Fairmont, W. Va., bituminous, average of 63 analyses. [e]	.75	38.16	54.63	6.45	2.30	1.43	Coking [f] and steam coal.

[a] Ann. Rept. Geol. Survey Pennsylvania, 1885, pp. 313, 318.
[b] Rept. Geol. Survey West Virginia, Vol. 2, 1903, pp. 695, 696, 700.
[c] Rept. Maryland Geol. Survey, Vol. 5, 1906, pp. 631–633.
[d] Rept. Geol. Survey Pennsylvania, Vol. MM, 1879, pp. 21–22.
[e] Rept. Geol. Survey West Virginia, Vol. 2, 1903, p. 209.
[f] The phosphorus in these analyses ranges from 0.0019 to 0.037, averaging 0.0117.

It may be seen from these tables that the Bering River anthracite has no equivalent among the coals now being mined on the Pacific coast and that it compares favorably with Pennsylvania anthracite.

It ought to be put into the San Francisco and other Pacific coast markets at a cost far below that of eastern coal, in which case it should have no difficulty in entirely supplanting the latter.

The Bering River semibituminous (like part of the semibituminous coal from Matanuska River) is also better than anything that is being mined in the West. These coals are the equivalent of the Pocahontas, New River, and Georges Creek coals of the East and are eminently adapted for use on warships and for other purposes for which a high-grade, pure, "smokeless" steaming coal is required; and for these purposes will command a considerably higher price than any coal that is now being mined on the Pacific coast, or if offered at equal prices should readily drive the latter from the market.

Part of this coal will produce an excellent quality of coke, better in fact (except possibly regarding content of phosphorus, regarding which few data are available) than coke which can be produced from any of the Washington and Vancouver Island coals and equal to the coke from Crows Nest Pass. If an important smelter industry grows up in Alaska, as now seems possible, the Bering River coking coal should have the advantage, both in quality and in transportation rates, over any coking coal which is now being used on the Pacific coast.

PETROLEUM.

INTRODUCTION.

LOCATION OF THE OIL FIELD.

The Controller Bay petroleum field is located in the southern part of the mainland region discussed in this report. The localities at which there are indications of petroleum are confined to a belt about 25 miles long from east to west and 4 to 8 miles wide from north to south (see fig. 2). This belt is adjoined on the north in part by the Bering River coal field. Its southern border is formed by Controller Bay and the Pacific Ocean and by the alluvial flats on the east shore of Controller Bay. The eastern and western terminations are Bering Glacier and the Copper Delta, respectively.

GEOLOGIC CONDITIONS IN THE OIL BELT.

The rocks which outcrop within the oil belt, as shown on the geologic map (Pl. V, pocket), are chiefly the various members of the Katalla formation represented in the section of rocks south of Bering Lake as given on p. 37. In addition to these some of the metamorphic rocks, the Quaternary deposits, and the dikes described on pages 24-42 are represented. The structure has been described on pages 43-46.

DEVELOPMENTS.

Active attempts to produce petroleum in commercial quantities in this region have been made for the last five years. The first well was begun in the summer of 1901, but no oil was produced and no great depth was reached, as the tools were soon lost and the well abandoned. The next year (1902) the same people drilled another well and obtained some oil. Six wells were being drilled in 1903. The following year (1904) witnessed the greatest activity that the region has seen, eight wells being in progress. In 1905 and 1906 operations were restricted to two wells.

The result of these operations has been to obtain one well which yields a moderate amount of oil, another well which is capped, but in which the oil has at times a considerable pressure, and two more wells in which an unknown amount of oil stands near the top of the casing.

Drilling has proved to be very difficult and expensive and the results not as encouraging as had been hoped. These facts, together

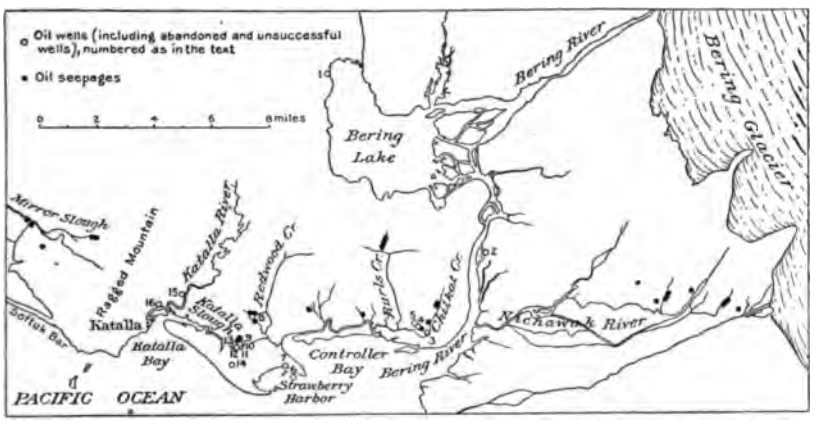


FIG. 2.—Map of Controller Bay oil field, showing position of wells and seepages.

with the uncertainty as to the amount of territory which one concern may legally control and the equally great uncertainty as to the conditions of the market, have led to a suspension of some of the more active operations.

OCCURRENCE OF PETROLEUM.

SEEPAGES.

GEOGRAPHIC DISTRIBUTION.

It may be seen from inspection of the map (fig. 2) that the seepages all occur within a long narrow belt extending from the edge of the Copper Delta to Bering Glacier, a distance of about 28 miles

from east to west. The belt is very narrow, not exceeding 4 miles at the widest known point, and is parallel to the north shore of Controller Bay, which has the same east and west direction as the larger aspect of the shore of the Pacific Ocean between Copper River and Yakutat Bay. The seepages at Cape Yaktag[a] are also reported to lie on a line having the same direction as this and practically coinciding with it in extended position. Several of the smaller groups of seepages, such as the group on Redwood Creek and at the head of Katalla Slough, those in the valleys of Burls and Chilkat creeks, and in the Nichawak region, have a distinct linear arrangement each running about N. 15° E. These lines coincide with the directions of the valleys in which they occur, and the relationship suggests that either the position of the valley and that of the line of seepages are due to the same cause or that the one is due to the other.

RELATIONS TO KINDS OF ROCK.

The oil of the seepages reaches the surface through a variety of rocks (see pp. 116–119). The seepages west of Katalla are associated with metamorphic rocks, the oil reaching the surface either through the joints and bedding or cleavage planes of the slate and graywacke or through surficial deposits which probably overlie such rocks. The presence of petroleum in rocks of this character is somewhat unusual and worthy of notice. Similar occurrences of small quantities of oil in metamorphic rocks are known in California and Washington, where the oil is considered to have migrated into the metamorphic rocks subsequent to their alteration. A similar explanation may hold for the Alaska occurrence. The writer would suggest as a possible explanation that the metamorphic rocks, which are known to be separated from the Tertiary shales by a fault (see p. 44), are overthrust upon the shales along a fault plane of low hade, and that the oil at the seepages west of Ragged Mountain is coming through the metamorphic rocks from underlying shales.

The seepages at the head of Katalla Slough and on Redwood, Burls, and Chilkat creeks are all in the soft shales which compose a large part of the Katalla formation (*g* of section on p. 37). Those between Redwood and Burls creeks are associated with conglomerates of presumably higher position (*e* of the section). Such of the seepages of the Nichawak region as have been seen by the writer are in shales which closely resemble those referred to above. The Yaktag seepages are said to be in Miocene sandstone and shales.

RELATION TO STRUCTURE.

The position of the seepages with reference to the structure is somewhat vague and uncertain. Those west of Katalla are on steeply folded and slightly metamorphosed rocks in which the detailed

[a] Locally known as Cape Yakataga.

structural features have not been determined. The group on Redwood Creek and Katalla Slough is apparently in close proximity to a fault. The Burls Creek group and the Redwood Creek group are near the axes of anticlines, the Redwood Creek anticline being probably broken near or west of its axis by a fault. The seepages between Burls and Redwood creeks are on monoclinal conglomerates. The general structure of the Nichawak region has not been determined, but the rocks have steep dips and are probably closely and complexly folded. The Yaktag region, which has not been visited by the writer, is said to have an anticline near and parallel to the coast, north of which the rocks have monoclinal northward dip. The seepages are said to occur on the north flank of the anticline, parallel to and not far from its axis.

It may be seen from the preceding paragraphs that, although small groups of seepages lie on local structure lines, yet the general distribution of all the seepages in a long, narrow, east-west belt diagonal to the structure and to the belts of outcrop of the various kinds of rock is unexplained. The existence and position of this belt, nevertheless, must have been determined by the stratigraphy and structure—if not by that of the surface rocks, then by that of some rocks which do not outcrop at that surface.

The rocks which outcrop within this region have been shown above to be for the most part unaltered Tertiary sediments, with smaller areas of metamorphosed rocks similar to those which probably compose the greater part of the Chugach Mountains and of the shores and islands of Prince William Sound. These older rocks are of undetermined age, but the weight of the evidence from all the wide region through which they extend indicates that they are Paleozoic. In this case there is an hiatus between them and the Tertiary rocks which is represented in neighboring regions by many thousand feet of strata. North of the Chugach Mountains in the valley of the Chitina River this interval is represented by about 4,000 feet of Triassic[a] sediments and 1,600 feet of Jurassic[b] beds. In the Matanuska Valley it is represented[c] by several thousand feet of Jurassic and Cretaceous rocks. On Cook Inlet and the Alaska Peninsula[d] over 2,000 feet of upper Triassic, 8,500 feet of Jurassic, and probably several thousand feet of Cretaceous rocks intervene between the metamorphosed Paleozoic and the slightly consolidated Tertiary beds.

---

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska. A special publication of the U. S. Geol. Survey, 1901, pp. 46–50.

[b] Mendenhall, Walter C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 52.

[c] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16–24.

[d] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. *America, vol.* 16, 1905, pp. 391–410.

The Jurassic rocks on the west shore of Cook Inlet and on the Alaska Peninsula yield petroleum[a] which is of the same character and composition as the Controller Bay oil, and very different from most of the Tertiary oil of California and other Pacific coast fields.

The inference naturally follows that the Controller Bay petroleum may be derived from Mesozoic strata which are buried beneath the Tertiary rocks. If such be the case a fault parallel to the coast and to the mountains will account for the position and character of the shore and will offer a zone of movement for the oil from its original source in the Mesozoic rocks below into its present apparent source in the Tertiary rocks at the surface. By such a fault the Tertiary rocks, closely folded when in immediate proximity to the mountains, might have overridden Mesozoic beds which were at a distance from the zone of disturbance, and hence not necessarily folded or disturbed. The oil could then come up along the fault planes and through joints from buried Mesozoic rocks of possibly simple structure into the complexly folded Tertiary rocks. The structure of the underlying rocks and the position of the fault or faults would determine the major east-west seepage belt, while the structure of the more intricately folded rocks at the surface would determine the details of the minor northeast and southwest groups of seepages. This hypothesis removes the difficulty of accounting for light-gravity oils in complexly folded and faulted rocks and explains the occurrence of the seepages in a narrow zone diagonal to the structure, parallel to the mountains along the general east and west shore line, and in line with the belt of seepages at Yakataga. It is a possibility which should be borne in mind in further local geological studies or in interpreting the position of apparent oil-sands in wells or at seepages.

DESCRIPTION OF THE SEEPAGES.

Petroleum seepages and gas springs are very numerous in many parts of the oil belt, and at some of them the flow of oil or of gas is large.

Several large oil seepages were seen by the writer on the banks of Mirror Slough, near the mouth of Martin River. The petroleum reaches the surface from the clay and mud of the valley floor, and a large amount has accumulated in the pools on the swampy surface and in the soil. The nearest outcrops of hard rock are sandstones or graywackes, probably the same as those on Wingham Island and in Ragged Mountain, and if so of pre-Tertiary and probably Pale-

[a] Martin, G. C., The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 37-59; Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128-139.

ozoic age. It seems almost certain that oil came from these rocks. Seepages were also seen near the head of Mirror Slough at the base of Ragged Mountain. The oil here reaches the surface through soil immediately underlain by either glacial drift or by talus or landslide débris. The underlying rocks are probably the slate or graywacke referred to above. Another seepage about 1 mile south of this point, in the canyon immediately north of Bald Mountain, was visited by the writer. The oil was here seen oozing in small quantities directly from the joints and bedding planes of the steeply dipping slate, chert, and graywacke.

Oil is reported to have been seen in large amounts at the time of the earthquake, 1899, on the surface of the water of the small ponds and the creek at the south end of the town of Katalla. The surface material consists of rock débris largely from Ragged Mountain, underlain by the soft shales of the Katalla formation.

Numerous and copious seepages are to be seen at the head of Katalla Slough. The oil impregnates the soil very completely at many points and has accumulated in large amounts on the surface. These accumulations are chiefly of oil, and are not residues as at the California brea deposits. No outcrops are near but the underlying rock is almost certainly the soft shale referred to above and probably has a steep dip.

On the west slope of the valley of Redwood Creek about 1½ miles northwest of the mouth of the creek and near a well (No. 8, fig. 2, p. 113), oil can be seen coming directly from soft, fissile, iron-stained shales. The shale has been broken into small angular fragments and recemented by ferruginous material. This condition is frequent at or near seepages in these shales, but it is not known whether it is a surface condition connected with erosion or whether it indicates crushing of the rocks at a depth below the surface during the process of folding or faulting. Here, as at many other seepages, sulphur springs are associated with the oil. Another seepage was seen near the headwaters of Redwood Creek.

It is reported that oil may be seen at low tide in the beach sands on the north shore of Strawberry Harbor. The rocks in the vicinity are sandstone and shale, probably belonging much higher in the stratigraphic column than the soft shale at the seepages previously described.

There are several seepages along the wagon road which leads from the head of Katalla Slough to the mouth of Bering River. Two of these are located about a mile and a half west of Burls Creek and close to the road. The amount of oil at one of these is large. The nearest visible rock is steeply dipping conglomerate which outcrops a

few feet away, but the oil can be seen only on the surface of the soil, the direct source not being visible.

The upper part of the valley of Burls Creek contains many seepages at which the oil oozes directly from steeply dipping shales which here contain a large amount of glauconite grains, which gives the rock a bright-green color. Thin sections show abundant casts of Foraminifera and diatoms. Large calcareous concretions are abundant and often take the form of septaria nodules with calcite fillings. Organic remains consisting chiefly of mollusks and crabs are frequently seen in the concretions. The soft shale is also rich in organic material, some beds being so dark as to suggest in appearance impure coal. No coal was seen by the writer in these rocks, either at this locality or elsewhere. The rocks at this point seem to be very strongly impregnated with oil and seepages are numerous, but large surface accumulations are rare. Broken shale recemented by ferruginous material was seen here as on Redwood Creek.

Some seepages with considerable surface accumulation of oil were seen along the edge of the tidal flat, close to the wagon road, half way between Burls Creek and the mouth of Bering River. Outcrops were absent in the immediate vicinity, but fragments of shale indicated the presence of such rock.

Several seepages have been reported from Chilkat Creek. The largest one seen by the writer is in the west bank of the creek, 1½ miles above the forks of the wagon road. The oil reaches the surface through soft brecciated shale with a steep westerly dip. The seepage is associated with a black sulphur spring.

Many seepages have been reported in the group of hills centering around Mount Nichawak. Those seen by the writer were small, but the oil issued directly from the rock, which is shale resembling that at the seepages west of Bering River. Others are reported to be located on the banks of a small lake, which is said to be covered at times with oil.

Other seepages have been reported from various parts of the Controller Bay region, but they have not been seen by the writer.

Reference should be made to the seepages in the vicinity of Cape Yaktag, about 75 miles east of Controller Bay. The amount of oil is said to be very large, there being a continuous flow from several of the seepages, one of which has been estimated to yield several barrels of oil per day. The oil is said to come directly from the rocks, which are shales and sandstones of Miocene age, the seepages being in a line along the crest of an anticline parallel to the coast.

Inflammable gas comes to the surface of the water in large amounts in several places. The largest of the "gas springs" seen by the

writer are in Mirror Slough and in Katalla River. The former is sufficient to furnish a large continuous flame. The composition of the gas is not known. It issues from the mud on the bottom of the slough.

WELLS.

The wells in which oil has been obtained in this region are so few that they throw little or no light on the problem of the occurrence of oil. A flow of oil had been obtained in one well (No. 10, fig. 2) and less quantities in three others (Nos. 5, 8, and 13). All of these wells are close to seepages and are on the outcrop of the upper shales of the Katalla formation. They are all on lines of seepages having a north-northeast to south-southwest direction, and are all on the steeply dipping northwest flanks of anticlines and possibly on or near lines of faulting. It is unfortunate that no other wells have been drilled in similar positions on the structural lines alluded to above. Such wells might not be successful, but they would test the possible theory that the above-mentioned lines have something to do with the distribution of the oil.

The net result of the drilling has been to show the existence of moderate amounts of oil in at least part of the territory. The wells are neither numerous enough nor deep enough to determine the outline of the pools and the area of productive territory, or to show whether the oil exists in sufficient quantity to pay for exploitation. They have demonstrated the difficulty and expense of drilling, and the need of ample resources and careful management. The existence of oil in remunerative quantities has neither been proved nor disproved. The evidence from the existing wells, like that of the seepages, is sufficient to warrant further testing, if it be done intelligently and carefully by companies strong enough to exploit large areas on a scale which permits of wholesale economies, and also strong enough to risk their capital on what must certainly be regarded as a speculation rather than an investment.

The following list contains an account of each well that has been drilled in the district. The numbers refer to the geographic location of the wells, as shown on the map (fig. 2, p. 113).

No. 1. West shore of Bering Lake. The surface rocks are sandy shales, presumably underlying the coal-bearing rocks. Dip, 12° to 35° NW. Well begun in 1905, but interrupted by accidents to machinery. Depth, several hundred feet.

No. 2. East shore of Bering River. Begun in 1903. Abandoned without reaching bed rock at depth of 580 feet because of difficulty of sinking casing through the mud.

No. 3. Chilkat Creek. Drilled in 1904 to depth of several hundred feet. No information available.

No. 4. Edge of tidal flats 1 mile west of mouth of Bering River. Drilled in 1904 to depth of several hundred feet.

No. 5. Edge of tidal flats a short distance northwest of No. 4. Drilled in 1904 to depth of several hundred feet. Oil now stands near top of casing. Small but continuous flow of gas. Amount of oil not known.

No. 6. Strawberry Harbor. The derrick was built on piling about 1,000 feet offshore. Casing sunk deep into the mud in 1904 without reaching bed rock.

No. 7. Strawberry Harbor. Drilled several hundred feet in 1904 without obtaining oil.

No. 8. Redwood Creek. Drilled to depth of several hundred feet in 1904. Oil now stands about 20 feet below the top of the casing. Quantity not known.

No. 9. Near head of Katalla Slough. Drilled to unknown depth in 1904. No oil as far as known.

No. 10. Near head of Katalla Slough. Drilled in 1902 to depth of 366 feet, when a flow of oil was obtained. Drilled to 550 feet in 1903 without further results. In 1904 this well was pumped for fuel at the other wells of the same company. It is now capped, the oil oozing from around the casing. The following is a record of this well, as reported by the Alaska Steam Coal and Petroleum Syndicate, and published by F. H. Oliphant:[a]

Record of 550-foot well near head of Katalla Slough.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface drift	6	6
Decomposed shale	10	16
Light-colored shale	140	156
Fine-grained sandstone, containing 6-inch bed of coal	18½	174½
Dark shale, very hard, including 6 inches of quartz containing iron pyrites	190½	365
Oil sand; flow of oil	1	366
Length of 12-inch casing	.....	220
Length of 9⅝-inch casing	.....	340

Numerous small showings of petroleum and natural gas were encountered as the drill proceeded down, and at 366 feet a large quantity of oil was developed, which flowed some petroleum. The well is said to have continued to flow until capped.

No. 11. Near head of Katalla Slough. Drilled in 1901 and abandoned because of loss of tools.

No. 12. Near head of Katalla Slough. Drilled in 1903 to unknown depth.

[a] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

No. 13. Near head of Katalla Slough. Drilled in 1904 to unknown depth. Now capped, the oil squirting at times in strong jets from the casing.

No. 14. Between head of Katalla Slough and Cave Point. Drilled in 1903 to 1,710 feet and abandoned because limit of outfit was reached.

No. 15. Katalla River. Casing sunk to depth of 280 feet in 1903 without reaching bed rock.

No. 16. Near Katalla. Two holes drilled in 1904 to 1906 to a depth of about 1,500 feet. Work still in progress.

CHARACTER OF THE PETROLEUM.

A sample collected by the writer from a well (No. 10 in list, on p. 120) near the head of Katalla Slough was tested by Penniman & Browne, of Baltimore, with the following results:

Test of petroleum from Katalla Slough.

	Per cent.	Specific gravity at 15.5° C.
Distillation by Engler's method:		
Benzine (80° to 150° C.)	21	0.7573=54.9° Baumé.
Burning oil (150° to 300° C.)	51	.8204=40.6° Baumé.
Residuum (paraffin base)	28	.9096=23.9° Baumé.
Sulphur	Trace.	
Specific gravity of crude oil	.....	.828 =39.1° Baumé.

The burning oil was purified by concentrated sulphuric acid and soda, the volume of acid used up being too small to measure. The purified burning oil was put into a small lamp, where it burned dry without incrusting the wick or corroding the burner, and without any marked diminution of flame. The burning oil compares very favorably in these respects with Pennsylvania oil prepared in the same way.

The following analysis of this petroleum was published by Mr. Oliphant:[a]

Analysis of petroleum from Katalla Slough well.

Specific gravity at 60° F. 0.7958, equal to 45.9° Baumé.
Cold test; did not chill at 3° F. below zero.

Distillation:	Per cent.
Below 150° C., naphtha	38.5
150° to 285° C., illuminating petroleum	31
Above 285° C., lubricating petroleum	21.5
Residue, coke and loss	9

The following tests of Controller Bay and Yaktag oil have been published by Redwood[b] from results obtained in his laboratory.

[a] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

[b] Redwood, Sir Boverton, Petroleum, vol. 1, 2d ed., 1906, p. 198.

Physical properties of crude petroleums.

Locality.	Specific gravity.	Flashing-point (Abel test).	Color.
		°F.	
Buris Creek	0.942	234	Dark reddish brown.
Johnstone Creek, 1	.964	200	Dark brown.
Johnstone Creek, 2	.879	178	Do.
Poul Creek (lowest)	.970	250	Do.
Poul Creek (top, west)	.881	67	
Poul Creek (upper)	.914	156	Do.
Katalla Meadow, 1	.929	240	Do.
Katalla Meadow, 2	.901	156	
Katalla Meadow, 3	.874	156	
Katalla Meadow, 4	.869	152	
Katalla Meadow, 5	.961	266	
Bore hole at Katalla, 120 feet (1902)	.802	Below 60	Dark red.
Bore hole at Katalla, 355 feet (1902)	.790	Below 60	Do.
Oil Creek	.855	108	Dark brown.
Morrison Creek	.991	270	Do.
Argyll Creek (Icy Bay)	.962	310	Do.
Yakogelty	.937	246	Do.
Crooked Creek	.921	172	Do.

Commercial products of crude Alaska petroleum.[a]

Specific gravity.	Petroleum spirit (benzine).	Kerosene.	Intermediate and lubricating oils, with solid hydrocarbons.	Coke.
	Per cent.	*Per cent.*	*Per cent.*	*Per ct.*
0.869	.....	19.0	78.6	1.7
.914	.....	9.0	87.6	2.7
.800	24.8	53.9	16.7	1.2

[a] Redwood, Sir Boverton, op. cit., p. 214.

The analyses given below were published by Stoess:[a]

The following analysis was made in Seattle from a sample of the crude oil taken from the well at Katalla:

Analysis of oil from Katalla well.

Specific gravity, 0.800.

Naphtha	34.4
Illuminating oil	34.4
Lubricating oils	16.5
Coke and residue	14.5

Another analysis [possibly the same as that published by Oliphant and quoted above], made in Los Angeles, Cal., gave—

Analysis of oil from near Katalla.

Specific gravity	0.7957 (45.9° B.)
Cold test	Not chilled at 3° below zero
Naphtha	38.5
Illuminating oil	31.0
Lubricating oils	21.5
Coke and loss	9.0

Oil has a flash test of 70° to 80°. Oil is light green in color.

[a] Stoess, P. C., The Kayak coal and oil fields of Alaska: Min. and Sci. Press, vol. 87, 1903, p. 65.

The results of all available analyses and tests on oils from the Controller Bay and Yaktag regions are brought together in the following table:

Summary of analyses and tests of Controller Bay and Yaktag petroleum.

Locality.	Color.	Specific gravity.	Gravity, Baumé.	Flashing-point.	Benzine.	Kerosene.	Lubricating oil.	Residue: Coke and loss.
			°	° F.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Katalla Slough, well No. 10	.....	0.8280	39.1	.....	21.0	51.0	28.0	
	.....	.7958	45.9	.....	38.5	31.0	21.5	9.0
	Light green	.7957	47.9	70-80	38.5	31.0	21.5	9.0
	.....	.800	.....	.....	34.2	34.4	16.5	14.5
	Dark red	.802	.....	Below 60.	.....	.....	.....	.....
	....do	.790	.....	Below 60.	.....	.....	.....	.....
(?)	.....	.869	.....	.....	.....	19.0	78.6	1.7
(?)	.....	.914	.....	.....	.....	9.0	87.6	2.7
(?)	.....	.800	.....	.....	24.8	53.9	16.7	1.2
Burls Creek	Dark reddish brown.	.942	.....	234	.....	.....	.....	.....
Johnstone Creek	Dark brown	.964	.....	200	.....	.....	.....	.....
	....do	.879	.....	178	.....	.....	.....	.....
Poul Creek	....do	.970	.....	250	.....	.....	.....	.....
	....do	.881	.....	67	.....	.....	.....	.....
	....do	.914	.....	156	.....	.....	.....	.....
Katalla Meadow	....do	.929	.....	240	.....	.....	.....	.....
	.....	.901	.....	156	.....	.....	.....	.....
	.....	.874	.....	156	.....	.....	.....	.....
	.....	.869	.....	152	.....	.....	.....	.....
	.....	.961	.....	266	.....	.....	.....	.....
Oil Creek	Dark brown	.855	.....	108	.....	.....	.....	.....
Morrison Creek	....do	.991	.....	270	.....	.....	.....	.....
Argyll Creek, Icy Bay	....do	.962	.....	310	.....	.....	.....	.....
Yakogelty	....do	.937	.....	246	.....	.....	.....	.....
Crooked Creek	....do	.921	.....	172	.....	.....	.....	.....

Many of the samples consisted of seepage oil and probably have not yielded as large a proportion of the more volatile constituents as would be obtained from "live" oil from the wells.

The results of the tests may be compared with those of other petroleums in the following table:

Tests of petroleum from Alaska and other fields.

	Alaska.[a]	Alaska.[b]	Pennsylvania.[c]	Ohio.[d]	Colorado.[e]	Mexico.[f]	Beaumont, Tex.[g]
Benzine (80°-150° C.)	21	38.5	16.5	10	16	10	2.5
Burning oil (150°-300° C.)	51	[h] 31	54	50	40	60	40
Residuum	28	[h] 30.5	29	40	44	30	57.5
Sulphur	Trace.	.....	.....	.....	.....	.....	1.7
Gravity	39.1° B.	45.9° B.	.....	.....	43° B.	.....	22° B.

[a] Penniman & Browne for this report.
[b] Oliphant, F. H., The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.
[c] Peckham, S. F., Report on Petroleum, p. 365.
[d] Woodman, Durand, Jour. Am. Chem. Soc., Vol. 13, p. 168.
[e] Oliphant, F. H., Petroleum: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 250.
[f] Stillman, T. B., Engineering Chemistry, p. 364.
[g] Hayes, C. W., and Kennedy, W., Oil fields of Texas-Louisiana coastal plain: Bull. U. S. Geol. Survey No. 212, 1903, pp. 146-151.
[h] See above.

The petroleum is clearly a refining oil of the same general nature as the Pennsylvania petroleum. It resembles the latter in having a high proportion of the more volatile compounds and a paraffin base and in containing almost no sulphur. The proportions of the several constituents given in the tables above do not necessarily represent the full amounts that could be obtained in practice by different treatment.

PRINCIPLES GOVERNING THE OCCURRENCE OF PETROLEUM.

The four great problems of the geologic occurrence of petroleum are the origin of oil, the movements of oil in the rocks, the stratigraphic and structural distribution of the existing accumulations of oil, and the determination of the location and area of valuable accumulations from the known facts of surface geology.

These problems are stated above in order of increasing importance from the point of view of immediate utility. The last problem can be determined by expensive practical testing with drill or by the solution of the first and second problems, together with a complete and accurate knowledge of the areal geology of the region in which the occurrence of oil is suspected. In the present condition of our knowledge drilling is the only certain way of determining this problem. But all knowledge gained in this way, as well as all facts concerning the geology of the oil-bearing rocks, lead us nearer to the solution of the other problems and hence hasten the time when we can determine within reasonable limits the presence of oil from our knowledge of how oil originates and how it accumulates. The first and second problems are consequently the problems of greatest ultimate importance, and should be given at least equal weight in a public geologic investigation with the other or immediate commercial problems.

Petroleum occurs in rocks of practically all ages from the oldest Paleozoic to the Recent. All known productive bodies of oil are in rocks of sedimentary origin, such as sandstones or sands, shales or clays, limestones, and conglomerates. Minute quantities of oil have, however, been seen in volcanic or other crystalline rocks.

The origin of petroleum may be explained according to one of two theories. The oil may be of organic origin, having been derived from animal or vegetable matter which was associated with the mineral constituents of the rocks at the time they were deposited; or it may be of inorganic origin, having been formed by the chemical action of water on the formerly unoxidized mineral constituents of the rocks. The prevalent scientific opinion is in favor of the organic theory for the origin of the larger and more widespread accumulations of petroleum.

The movement of petroleum in the rocks is controlled by the following factors: The direct action of gravity, capillary attraction,

the presence of water, gas pressure, and the distribution of channels or zones through which the oil can move.

The effect of the direct action of gravity is to cause oil to go down as far as the rocks are porous, dry, and not too warm for the oil to exist as such. It will sooner or later be stopped in this downward movement by an impervious stratum (either a bed of close-textured rock or a bed filled with water), and will then move laterally along the upper surface of that stratum to its lowest point, where it will accumulate.

The effect of capillary attraction is to cause the oil to be diffused somewhat throughout the rocks in all directions, provided the rock is dry and of the right texture to permit capillary movement. The directions in which it will move will be controlled by the distribution of porous rock and water, and will be modified by gravity and the other factors here discussed.

The presence of water causes an upward movement of the oil. The essential conditions for such movement are a porous rock containing both water and oil and a lower limit[a] beyond which the water can not go. The water, because of its greater density, seeks a lower level than the oil and forces the latter upward until either the demand of all the water for space is satisfied or until the oil is checked in its upward movement by an impervious stratum. In the former case the oil rests on the surface of the water in a state of equilibrium; in the latter case it is confined under pressure with a potential upward force.

Gas pressure tends to drive the oil in any unblocked direction. The requisites for oil movement caused by gas are the presence of gas, either in a contiguous body to the oil or being given off from or within the oil, and an impervious bed above the gas and through which it can not pass. The gas then tends to accumulate on the upper surface of the oil and to force the oil downward in the direction of least resistance, which may be either vertical or have a lateral component. The oil would already have been in the lowest available space,[a] so further downward motion implies the displacement of water. The motion continues until there is equilibrium between the expansive pressure of the gas and the hydrostatic pressure of the water. The oil is then confined between these forces and will escape under pressure at the first opportunity.

The most favorable conditions for the occurrence of petroleum over large and regular areas are the following:

1. A large and widely distributed original source of oil-yielding material.

---

[a] If the liquids have not already reached this lower limit, the case is considerably modified, and the exact condition can not, in the present state of our knowledge, be positively asserted.

2. Thick, extensive, and regular porous beds in which the oil can move freely and accumulate.

3. Impervious beds above and below the porous beds.

4. Small angles of dip and fairly regular structure.

5. Absence of deep fracturing or of irregularities of structure.

6. Absence of water in the rocks if the oil-bearing beds are synclinal, or presence of a moderate amount of water if they are anticlinal.

Such conditions are favorable to the occurrence of petroleum in large, regular, and easily outlined pools, to moderately large production and long life of the wells, and to a large degree of certainty in oil prospecting.

These conditions probably nowhere exist in their entirety, at least not over any broad area. Some of the Mississippi Valley and Appalachian oil fields come nearer to satisfying these conditions than any others in North America. It is very evident that few of these conditions are met in the Controller Bay region, so nothing will be gained from further comparison with regions in which simple structure predominates.

Some of the California,[a] Wyoming,[b] and Colorado[c] oil fields are characterized by complex and broken structure, in this respect being not unlike the Controller Bay region. These western fields show that it is possible for large accumulations of oil to exist in rocks with steep dips, irregular folds, and large faults. They show that the structure does not make it impossible for oil to exist in quantity in the region under discussion, but they show also the difficulties of drilling and of locating the pools in such a field, and demonstrate very clearly the need of careful operating and the risks which are necessarily involved.

EXPLOITATION.

LOCATING POOLS.

If oil is found in quantity it will almost certainly be in circumscribed areas, and the location and boundaries of these will be of the utmost importance in the development of the field. The position, size, and shape of these productive areas can not be foretold in advance of all drilling or at the present stage of development. The

[a] Eldridge, G. H., and Arnold, Ralph, The Santa Clara, Puente Hills, and Los Angeles oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907, 266 pp. Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, California: Bull. U. S. Geol. Survey No. 321, 1907, 91 pp. Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California: Bull. U. S. Geol. Survey No. 322, 1907, 161 pp.

[b] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907, 178 pp.

[c] Fenneman, N. M., Geology of the Boulder district, Colorado: Bull. U. S. Geol. Survey No. 265, 1905, 101 pp.

wells which have been drilled in this region are so few, most of them are so shallow, and so little oil has been obtained, that they give almost no light on the occurrence of oil in the rocks. But if at least one area were outlined wholly or in part by the known position of productive and nonproductive wells it would then be possible to determine the relation of the occurrence of the oil to the geology, and from the known facts of the geology to outline other possible productive areas in advance of drilling. For this reason it is of the utmost importance to obtain complete and accurate records of all wells and to use the information and experience thus gained in locating subsequent wells.

DIFFICULTIES OF DRILLING.

Crooked holes.—Much difficulty has been encountered in keeping the wells vertical, and delay and expense have resulted from the necessity of frequently reaming out the holes in order to straighten them. The crooked holes are the natural result of the steep inclination of the rocks with frequent alternations from hard to soft beds. Whenever the drill passes from a soft rock to a harder one dipping at a steep angle the drill tends to be deflected and a crooked hole results. This difficulty will always be encountered in this region and will increase the time and cost of drilling. The difficulties should, however, become less in the future, for the tendency of the drill to deflect can be lessened by drilling slower when the deflecting bed is struck and by special shaping of the tool, and the holes can be straightened more quickly when the drillers are better acquainted with local conditions.

Caving.—When a well in soft or fractured rock stands uncased too long, the rock caves in, often burying and frequently causing the loss of the tools, and sometimes making it necessary to abandon the well. Much delay has been caused in this way at most of the local wells, and it has added greatly to the cost of drilling. It has been impossible on this account to drill several of the wells as deep as they would otherwise have gone. The only remedy is to case the well at the proper time, and when the drillers know better the rocks with which they are dealing they will be able to anticipate the caving and introduce casing when it is needed. Conditions may thus be expected to improve in the future, making the cost less and the speed greater, and making it possible to sink wells to greater depths.

Water.—The rocks of this region are full of water and consequently large amounts are encountered in all the wells. This is undesirable for two reasons: The pressure of the column of water in the well keeps the oil back in the rocks and prevents it from coming out into the well, and the water reduces the effective weight of the drill and acts as a cushion between the drill and the rock, in

both ways reducing the power of the blow. The only remedy is in casing off the water, which can not be done too often without reducing the size of the hole to undesirable dimensions and finally limiting the depth to which it can be drilled without pulling the casing and going back and reaming out the hole.

Remoteness from supplies.—The remoteness of this region from a base of supplies not only increases the cost of labor and of freight, but also makes it necessary either to carry an exceptionally large equipment of fishing and repairing tools and of general supplies, or to be subject to delays in ordering special tools from a long distance. Conditions will improve in this respect with better facilities for communication and transportation, and can also be bettered if machine shops and supply depots are established, as they will be if the presence of productive oil territory is shown.

Inexperience with local conditions.—The difficulties caused by the lack of experience of the drillers with the rocks of the local section have already been alluded to. They may be summarized as including failure to drill slowly or to dress the tools so as to avoid deflecting the drill on hard, steeply inclined surfaces; failure to note the crookedness of the hole and remedy it promptly; ignorance of local caving strata and consequent failure to case in time to prevent cavings; and failure to secure proper and adequate outfit and supplies.

Cost of labor and transportation.—The cost of drilling has been very largely increased, over what it would be in more favored and better established oil fields, by the high cost of labor and of transportation of men and of freight. Not only are the drillers paid higher wages than they would receive at most localities, but the unskilled labor receives excessive pay. It is highly probable that, when conditions become more settled and work is done on a larger and more permanent scale, wage conditions will become more normal and transportation charges will be reduced.

SHIPMENT AND MARKETS.

If petroleum is produced in commercial quantities a new set of problems concerning its disposal will arise. All the petroleum of the region, so far as known, is a refining oil of high grade, for which there is a good demand on the Pacific coast. The content of extremely volatile constituents, such as gasoline, is so great that it is questionable whether the oil can be safely shipped in bulk without some refining. There are plenty of good sites for refineries in the immediate vicinity of the wells. If a harbor in the vicinity of Katalla or elsewhere in the Controller Bay region, is utilized, it will be a very simple matter to transport the oil from the wells to the wharves by short pipe lines on a practically level grade. If no harbor in the immediate vicinity can be used it will be necessary to ship from Orca Bay

or elsewhere on Prince William Sound, a distance of about 80 miles westward and across Copper River. The grades to Orca are almost nothing and there will be no difficulties except crossing Copper River. The distances from Katalla and from Orca to Seattle by the steamer route, "outside way," are about 1,250 and 1,350 statute miles, respectively.

CONCLUSIONS.

Geographic conditions are such as to cause heavy initial expense of prospecting and drilling, but admit of permanent improvements which will make these conditions much better without great engineering difficulties or excessive cost.

The geology is complex and difficult to interpret and does not show definitely the relation of the occurrence of the petroleum to the stratigraphy and structure. The known facts of the local geology are unfavorable to the presence of productive bodies of oil, and indicate that if oil is found in quantity the distribution of the productive areas will be very irregular and difficult to locate. However, if future developments confirm the theory of an overthrust along the coast (pp. 45–46, 115–116), separating the complexly folded rocks at the surface from rocks of simpler structure below, conditions may be found to be much more regular and more favorable for the development of a good oil field than the surface conditions indicate. This theory is, however, not proven, and is suggested merely as a possibility.

The surface oil showings (seepages), though widespread and copious, are not conclusive evidence of the occurrence of productive oil pools. They are apparently more promising than any of the other known geologic features of the region. The only safe conclusion to be drawn from them is that they indicate the possibility of productive oil areas in the vicinity.

Operators and investors who may not be familiar with local conditions will do well to be governed by the following suggestions:

1. They should be certain that legal title can be obtained to a sufficient area to make it possible to sink many test wells under widely differing conditions, and to permit a large enough probable production to pay for heavy initial expenditures and large permanent improvements.

2. They should have enough capital to be able (*a*) to purchase in quantity and at low rates; (*b*) to build good roads and other improvements and thus reduce cost of operating; (*c*) to carry a large stock of tools and supplies, in order to avoid costly delays in drilling and to be able to drill deep; (*d*) to secure the best professional advice and good drillers; (*e*) to drill many test wells without hope of immediate profit; (*f*) to market the product in the face of the existing conditions in the petroleum industry; and (*g*) to afford to lose the investment.

3. The first wells should be located on the strike and at no great distance from producing wells, or down the dip from a good seepage and at such varying distances that the rocks outcropping at the seepage will be encountered at depths of from a few hundred feet to the limit (in depth) of drilling.

4. Subsequent wells should be determined in position by the location of existing wells and by the structure. With respect to productive wells, they should be along the strike and close to [a] the wells; while with respect to nonproductive wells they should be either not along the strike and at a short distance, or along the strike and at a considerable distance, from the wells.

5. Drillers and tool dressers should be obtained from regions where there is difficulty in keeping the holes straight.

6. If oil is obtained, it will probably be down the dip, rather than up the dip from a seepage; in shallow wells near a seepage, in deeper wells farther from a seepage.

BIBLIOGRAPHY.

The following lists of publications embrace not only those containing references to the geology and mineral resources of this region, but also those relating to the coal, lignite, and petroleum of all parts of Alaska. The present volume contains so many references to the fuel resources and coal-bearing horizons of other parts of Alaska that it is felt that the broader bibliography will be useful. The publications whose titles are preceded by an asterisk (*) contain references to the geology or mineral resources of the Controller Bay region.

List of papers by members of the United States Geological Survey on coal, lignite, and petroleum of Alaska.

BROOKS, ALFRED H. * The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 515–571.

——— * The outlook for coal mining in Alaska; Trans. Am. Inst. Min. Eng., bimonthly bulletin No. 4, 1905, pp. 683–702.

——— * The production of coal in 1904; Alaska: Mineral resources U. S. for 1904, pp. 112–114 (of separate), 452–454 (of complete volume).

COLLIER, A. J. The coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, 71 pp.

——— Coal resources of the Yukon Basin, Alaska: Bull. U. S. Geol. Survey No. 213, 1903, pp. 276–283.

——— The coal fields of Cape Lisburne, Alaska: Am. Geologist, vol. 34, 1904, pp. 401–402.

——— Coal fields of the Cape Lisburne region: Bull. U. S. Geol. Survey No. 259, 1905, pp. 172–185.

——— Geology and coal resources of Cape Lisburne region, Alaska: Bull. U. S. Geol. Survey No. 278, 1906, 54 pp.

[a] The distance should vary with the porosity of the containing horizon.

DALL, W. H. Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 763–906.

MARTIN, G. C. * Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382.

——— * The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, 64 pp.

——— * Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139.

——— * Bering River coal field: Bull. U. S. Geol. Survey No. 259, 1905, pp. 140–150.

——— * Markets for Alaska coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 18–29.

——— * The distribution and character of the Bering River coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 65–77.

——— Preliminary statement on the Matanuska coal field: Bull. U. S. Geol. Survey No. 284, 1906, pp. 88–100.

——— A reconnaissance of the Matanuska coal field, Alaska, in 1905: Bull. U. S. Geol. Survey No. 289, 1906, 36 pp.

——— * The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 40–46.

——— * Petroleum at Controller Bay: Bull. U. S. Geol. Survey No. 314, 1907, pp. 89–103.

PAIGE, SIDNEY. The Herendeen Bay coal field: Bull. U. S. Geol. Survey No. 284, 1906, pp. 101–108.

STONE, R. W. Coal resources of southwestern Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 151–171.

——— Coal fields of the Kachemak Bay region: Bull. U. S. Geol. Survey No. 277, 1906, pp. 53–73.

List of papers by members of the United States Geological Survey containing briefer references to the coal, lignite, and petroleum of Alaska.

BARNARD, E. C. Report of the Fortymile expedition: Maps and descriptions of routes of exploration in Alaska in 1898, a special publication of the U. S. Geol. Survey, 1899, p. 81.

BROOKS, ALFRED H. The mining industry in 1905: Bull. U. S. Geol. Survey No. 284, 1906, p. 9.

——— * The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, 327 pp.

DALL, W. H., and HARRIS, G. D. The Neocene of North America: Bull. U. S. Geol. Survey No. 84, 1892, pp. 232–268.

ELDRIDGE, G. H. The extreme southeastern coast; * The coast from Lynn Canal to Prince William Sound: Maps and descriptions of routes of exploration in Alaska in 1898. A special publication of the U. S. Geol. Survey, 1899, pp. 101–104.

——— A reconnaissance in the Susitna Basin and adjacent territory, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 1–29.

ELDRIDGE, G. H., and MULDROW, ROBERT. Report of the Susitna expedition: Maps and descriptions of routes of exploration in Alaska in 1898, a special publication of the U. S. Geol. Survey, 1899, pp. 22–24.

EMMONS, S. F. Alaska and its mineral resources: Nat. Geog. Mag., vol. 9, 1898, pp. 170–172.

——— Map of Alaska showing known gold-bearing rocks, with descriptive text, containing sketches of the geography, geology, and gold deposits and routes to the gold fields; a special publication of the U. S. Geol. Survey, 1898, pp. 39–44.

HOLMES, J. A. *Preliminary report of fuel-testing plant; Bull. U. S. Geol. Survey No. 290, 1906, pp. 229–231.

MENDENHALL, W. C. Report on the region between Resurrection Bay and the Tanana River: Maps and descriptions of routes of exploration in Alaska in 1898; a special publication of the U. S. Geol. Survey, 1899, p. 48.

——— The Kenai Peninsula: Maps and descriptions of routes of exploration in Alaska in 1898; a special publication of the U. S. Geol. Survey, 1899, pp. 109–110.

——— The Kodiak Islands; The Alaska Peninsula and the Aleutian Islands: Maps and descriptions of routes of exploration in Alaska in 1898; a special publication of the U. S. Geol. Survey, 1899, pp. 113–117.

——— A reconnaissance from Resurrection Bay to the Tanana River, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, 1898–99, pt. 7, p. 324.

——— A reconnaissance in the Norton Bay region, Alaska, in 1900: Special publication entitled "Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900," 1901, pp. 214, 215.

——— Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers: Prof. Paper U. S. Geol. Survey No. 10, 1902, p. 49.

——— Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, pp. 123–125.

MENDENHALL, W. C., and SCHRADER, F. C. The mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903, pp. 66–68.

MOFFIT, F. H. The Kotzebue placer-gold field of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 225, 1904, p. 80.

——— The Fairhaven gold placers, Seward Peninsula, Alaska: Bull, U. S. Geol. Survey No. 247, 1905, p. 67.

OLIPHANT, F. H. * Petroleum, in Mineral Resources U. S. for 1897: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1898, p. 110.

——— * Petroleum, in Mineral Resources U. S. for 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1899, p. 123.

——— * Petroleum, in Mineral Resources U. S. for 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1901, p. 167.

——— * Petroleum: Mineral Resources U. S. for 1900, U. S. Geol. Survey, 1901, p. 587.

——— * The production of petroleum in 1901, an extract from Mineral Resources U. S. for 1901: U. S. Geol. Survey, 1902, p. 208 (not in bound volume).

——— * Petroleum: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, pp. 582–584 (pp. 207–209 of separate).

——— * Petroleum: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, pp. 690–692 (pp. 179–181 of separate).

——— * Petroleum: Mineral Resources U. S. for 1904, U. S. Geol. Survey, 1905, pp. 724–726.

PAIGE, SIDNEY, and KNOPF, ADOLPH. A reconnaissance in the Matanuska and Talkeetna basins: Bull. U. S. Geol. Survey No. 314, 1907, pp. 104–125.

——— Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, 71 pp.

PARKER, E. W. *The production of coal in 1905: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, pp. 548–549 (pp. 100–101 of separate).

PRINDLE, L. M. The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, pp. 205–226.

SCHRADER, F. C. Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 485–486.

——— A reconnaissance in northern Alaska, across the Rocky Mountains, along Koyukuk, John, Anaktuvuk, and Colville rivers, and the Arctic coast to Cape Lisburne, 1901: Prof. Paper U. S. Geol. Survey No. 20, 1904, 139 pp.

SCHRADER, F. C., and SPENCER, ARTHUR C. * Geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, pp. 91–92.

SPURR, J. E. Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 380–382.

——— *A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 262–264.

TARR, R. S. The Yakutat Bay region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 63–64.

WALCOTT, C. D. Account of an investigation of the gold and coal deposits of southeastern Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 56–59.

WRIGHT, F. E. and C. W. Economic developments in southeastern Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 56–57.

WRIGHT, C. W. A reconnaissance of Admiralty Island, Alaska: Bull. U. S. Geol. Survey No. 287, 1907, pp. 151–154.

List of scattered papers of importance on Alaska coal, lignite, and petroleum.

ANON. The Cold Bay oil field: Eng. and Min. Jour., vol. 76, pp. 618–619.

DEPARTMENT OF THE INTERIOR. *Coal areas in the United States. S. Doc. 194, 59th Cong., 2nd Sess., 1907. [Includes maps of Alaska coal fields.]

GRIFFITH, WILLIAM. Report on the Matanuska coal field (private report), 1906, 40 pp., 8 maps, and many other illustrations.

——— * Kinds and occurrence of anthracite coal: Min. Mag., vol. 13, No. 3, 1906, pp. 219–220.

KIRSOPP, JOHN, Jr. * The coal fields of Cook Inlet, Alaska, U. S. A., and the Pacific coast: Trans. Inst. Min. Eng. (England), vol. 21, pp. 536–559.

PETROFF, IVAN. Alaska, its population, industries, and resources: Tenth Census of the United States, vol. 8, 1882, p. 87.

REDWOOD, Sir BOVERTON. * Petroleum, 2d ed., 1906, pp. 93, 178, 198, 214.

STOESS, P. C. * The Kayak coal and oil fields of Alaska: Min. and Sci. Press, vol. 87, 1903, p. 65.

INDEX.

A.

Page.

Acila, occurrence of..... 28, 29
Acknowledgments to those aiding..... 13-14
Age of rocks, discussion of..... 26-27, 37-41
Alaska, coal imports of..... 110-112
coal of, analyses of..... 109-110
character of..... 109
distribution of..... 63, 106-108
map showing..... 106
mining of..... 108-109
consumption of coal in..... 95-98
consumption of oil in..... 96
investigations in, policy of..... 7
Analyses. (*See* Coal; Petroleum.)
Andromeda grayana, occurrence of..... 35
Angulus, occurrence of..... 28
Anodonta, occurrence of..... 31
Anthracite coal, analyses of..... 84-88, 109
areas of..... 65, 91, 107
character of..... 81, 88, 92, 94, 111-112
definition of..... 88
distribution of..... 65, 90-91, 107
Aralia Jorgensi, occurrence of..... 34
Arca, occurrence of..... 31
Arctic slope, coal of..... 108
Alaska Peninsula, coal of..... 107
coal of, analysis of..... 109
geology of..... 115-116
Anaktuvuk River, coal of..... 107
coal of, analysis of..... 109
Argyll Creek, oil of, analysis of..... 123
oil of, character of..... 122
Arnold, Ralph, fossils determined by..... 30
on age of rocks..... 39
Arnold, Ralph, and Dall, W. H., on fossils.. 40
Arvesta Creek, fossils on..... 30
Astarte, occurrence of..... 46
Asterias, occurrence of..... 29
Astrangia, occurrence of..... 30
Astrodapsis, occurrence of..... 30
Atwood, W. W., aid of..... 13

B.

Balanus, occurrence of..... 46
Bald Mountain, oil near..... 117
Basalt, occurrence and description of..... 41
Basaltic glass, occurrence of..... 41
Base-levels, occurrence of..... 60, 64
Beach deposits, description of..... 52-53
Bela, occurrence of..... 29, 46

Page.

Belcher, Edward, explorations by..... 10
Bench marks, locations of..... 12-13
Benches, levels of..... 60
occurrence and description of..... 59-60
Berg Lakes, coal near, analyses of..... 84-86
coal near, sections of..... 67
description of..... 47-48
fossils near..... 35
geology at..... 30
terraces of..... 52
view at..... 46
Bering, Vitus, exploration by..... 9
Bering Glacier, description of..... 16, 46-48
marginal lakes of..... 47-48
moraine of..... 47, 50
views of..... 46
Bering Lake, coal near..... 65
coal near, analyses of..... 84-85, 87
sections of..... 79-80
description of..... 16, 55, 56
fossils near..... 28-29, 31
geology near..... 27, 30, 31, 40-41, 43, 52
oil well at..... 119
origin of..... 65
sections near..... 37
topography near..... 15
Bering River, coal on. (*See* Bering River coal field.)
description of..... 16-17, 55-56
fossils on..... 28-29, 35
geology on..... 27, 43, 52, 53, 62
oil near..... 118, 119-120
views on..... 54
Bering River coal field, coal of..... 65-112
coal of, analyses of..... 84-88, 109
area of..... 65-66, 107
character of..... 91-92, 101
map of..... Pocket.
structure in..... 42-43
figure showing..... 42
Bering Sea region, coal of..... 107, 108
Betula, occurrence of..... 29
grandifolia, occurrence of..... 35
prisca, occurrence of..... 35
Bibliography..... 130-133
Bituminous coal, analyses of..... 109
character of..... 89, 112
coking of..... 82
distribution of..... 90-91, 107

Page.
British Columbia coal, analyses of..... 111
Brooks, A. H., aid of..... 13
preface by..... 7-8
Brooks, A. H., and Abbe, Cleveland, on Alaska climate..... 17-18
Buccinum, occurrence of..... 29,31
Bullaria, occurrence of..... 29,36
Burls Creek, fossils on..... 30
geology near..... 42,43,118
oil on..... 114,115,117-118
analysis of..... 123
character of..... 122

C.

Cætani Lake, character of..... 48
California coal, analysis of..... 111
production of..... 99
California petroleum, effect of, on coal trade.98-101
production of..... 99
Callista, occurrence of..... 30
Campbell, M. R., coal classification by..... 90
Campbell, Mount. (*See* Mount Campbell.)
Campbell River, description of..... 17,56
Cantwell River. (*See* Nenana River.)
Canyón Creek, coal near..... 65,90
coal near, analysis of..... 84-86
sections of..... 69-70
description of..... 16,56
fossils on..... 35
geology near..... 30,52
Carbon Creek, coal near..... 65
coal near, analysis of..... 87
coking of..... 82
sections of..... 76,77
geology on..... 31,43
section on..... 32
Carbon-hydrogen ratios, discussion of..... 90-91
Carbon Mountain, coal on..... 65,66,90
coal on, analyses of..... 84-86
sections of..... 67-70
coke and basalt silts on, view of..... 92
elevations on..... 58
geology of..... 31,35,36
Carbon-oxygen ratios, discussion of..... 91
Carbon Ridge, section on..... 35-36
Cardium, occurrence of..... 28,31
Cave Point, geology near..... 44
Charlotte Lake, coal near..... 65
coal near, analyses of..... 84-85
sections of..... 78
description of..... 56
faults near..... 43
fossils on..... 31,34
geology near..... 31,36,50
Charlotte Ridge, altitude of..... 58
geology at..... 35
Chezum, Mount, fossils near..... 36
Chilkat, description and location of..... 20
Chilkat Creek, fossils on..... 30
geology near..... 43
oil near..... 114,118,119
Chione, occurrence of..... 28
Chionella, occurrence of..... 28,29
Chistochina River, lignite at, analysis of..... 110
Chitina River, geology on..... 115
Chitistone River, lignite at, analysis of..... 110
Chrysodomus, occurrence of..... 30

Page.
Chugach Mountains, description of..... 15
foothills of..... 57
geology of..... 25
view of..... 16
Clark, W. B., fossils determined by..... 29
Clear Creek, coal on..... 90
coal on, analyses of..... 84-87
sections of..... 70-71
fossils near..... 31
geology on..... 30,41
Clementia, occurrence of..... 31,38
Climate, character of..... 17-19
Cloudiness, records of..... 17
Coal (*see also* Anthracite; Bituminous; Semi-anthracite; Semibituminous, Subbituminous; Lignite).
Coal, analyses of..... 83-88,102,109-111
analyses of, making of, methods of..... 83
areas of..... 65-66,106-107
beds of, description of..... 66-81
bibliography of..... 130-133
character of..... 81-92,109,112
chemical composition of..... 89-90
classification of..... 88-92
coking of..... 41,82,92,112
combustion of..... 82
comparison of, with other coal..... 92
competition of, with other coal..... 106-112
with petroleum..... 98-106
condition of..... 81-82,94
consumption of, in Alaska..... 95-98
crushing of..... 81-82,94
dip of..... 93
discovery of..... 14
distribution of, in Alaska..... 106-108
map showing..... 106
efficiency of oil and..... 102-104
gas in..... 94
geologic position of..... 66,92-93
imports of, to Alaska..... 97,111-112
markets for..... 95-112
mining of..... 92
occurrence of, investigation of..... 13
persistence of..... 93
petroleum and, competition of..... 98-106
physical properties of..... 81-82,94
prices of..... 104-105
sections of..... 66-81
shipment of..... 94-95
supply of..... 105-106
water in..... 94
Coal-bearing rocks, areas of..... 65-66
deposition of..... 63
distribution of, in Alaska..... 106-108
map showing..... 106
sections of..... 32-34
Coal field, map of..... Pocket.
Coast, description of..... 54
map of..... 10
Coke, natural, analysis of..... 84-85
occurrence of..... 41,70,71,92
view of..... 92
Coking tests, description of..... 82-83
Colville River, lignite at, analyses of..... 110
Commercial development, progress of..... 14-15
Contact, geologic, character of..... 26
of intrusives with coal..... 41,70,71,92

Page.
Controller Bay, description of..... 9
geologic map of.....Pocket.
harbor at..... 22
map of.....Pocket.
railway routes from..... 23
silting up of..... 65
surveys of..... 10-13
Controller Bay oil field, location of..... 112
map of..... 113
Conus, occurrence of..... 30
Copper Delta, surveys of..... 10
Cook Inlet region, coal of..... 107
geology of..... 115-116
Copper River, coal on..... 107
Cordova, railway from..... 23
Correlations, discussion of.....26-27, 37-41
Corylus Macquarrii..... 35
Cornus, occurrence of..... 35
Crassatellites, occurrence of..... 31
Crepidula, occurrence of..... 39
Cretaceous time, events of..... 62
Crest lines, accordance of..... 57-59, 60
Crooked Creek, oil from, analysis of..... 123
oil from, character of..... 122
Crustacea, occurrence of..... 38
Cunningham Ridge, geology of..... 35, 50
section on..... 34
Cyrene, occurrence of..... 31
Cytherea, occurrence of..... 36

D.

Dacite, occurrence of..... 42
Dall, W. H., fossils determined by..... 28-31
34, 36, 38, 39, 46
on age of rocks..... 38-39
Dall, W. H., and Arnold, Ralph, on fossils. 40
Daphnogene Kanii, occurrence of..... 29
Dawson, G. M., on Middleton Island..... 52
Dentalium, occurrence of..... 28, 29, 30, 31, 36
Diabase dikes, occurrence of.....41, 70, 71, 72
Dick Creek, coal near..... 66
coal near, analysis of..... 84-85
sections of..... 79, 80
geology on..... 31
Dikes, occurrence of..... 25, 41-42
Diplodonta, occurrence of..... 36
Distillation, products of..... 89
Dosinia, occurrence of..... 31
Drainage, description of..... 16-17, 55-56
Drilling, difficulties of..... 127-128
Dryopteris, occurrence of..... 35

E.

Eastern coals, analyses of..... 111
Edwardes River, description of..... 17, 56
Elevations, accordance of..... 57-59, 60
altitude of..... 15, 58
Eocene time, events of..... 63
Erosion, occurrence of..... 64
Explorations, history of..... 10-11

F.

Falls Creek, coal on, analysis..... 84-85, 87
coal on, sections of..... 79-80
Faults, occurrence and description of.26, 43-45, 116
Ficus, occurrence of..... 35

Page.
Field work, extent of..... 10-13
First Berg Lake, view of..... 46
Folds, occurrence and description of.. 25, 42-44, 64
Forests, character of..... 19-20
Fort Liscum, climate at..... 18
Fossils, occurrence of..... 28-30, 31, 34-35, 36, 38-40
Fox Island, harbor at..... 22
Frazer, Persifor, coal classification by..... 89
Fuel ratios, discussion of..... 89-91
Fusus, occurrence of..... 28, 30, 31, 36

G.

Gandil Mountain, altitude of..... 58
geology of..... 27, 52
topography near..... 15
Gandil River, position of..... 56
Gas, occurrence of in coal..... 94
Gas springs, occurrence of..... 118-119
Geology, description of..... 24-53
investigation of, difficulty of..... 7-8
topography and, relations of..... 25
Geology, economic, description of..... 65-130
Geology, historical, outline of..... 45-46, 51, 61-65
Glaciers, deposits of..... 50-53
description of..... 16, 46-50, 54
history of..... 64-65
occurrence of..... 16
Globigerina, occurrence of..... 26
Glycymeris, occurrence of..... 28
Grade Trail Cabin, fossils near..... 34
Grand Plateau Glacier, character of..... 47

H.

Hamilton, E. G., work of..... 14
Hamilton, Mount. (*See* Mount Hamilton.)
Haminea, occurrence of..... 36
Harbors, descriptions of..... 22
Hemiaster, occurrence of..... 29
Hemlock, distribution of..... 19-20
Hemithyris, occurrence of..... 30
Hey, Point. (*See* Point Hey.)
Hill, W. R., work of..... 14
Hills, distribution of..... 57
Historical geology, outline of..... 45-46, 51, 61-65

I.

Ice cliffs, view of..... 46
Igneous rocks, effect of, on coal..... 91-92
occurrence and description of..... 25, 41-42, 61
Interior region, coal of..... 108
Intrusions, time of..... 62
Isapis, occurrence of..... 28

J.

Japan, coal of, analyses of..... 111
Johnstone Creek, oil on, analysis of..... 123
oil on, character of..... 122
Juglans, occurrence of..... 35
Jurassic rocks, occurrence of..... 62, 115 116
Jurassic time, events of..... 62

K.

Kachemak Bay, lignite at, analyses of..... 110
Kanak Island, geology of..... 53, 55

Page.
Katalla, beach at 53
climate at 17
description of 20
geology near 53, 61, 117
oil near 117, 121
analysis of 122
character of 122
transportation at 20-21
Katalla Bay, description of 55
harbor at 15, 22
railways from 23
surveys of 10
Katalla formation, deposition of 63
fossils of 28-30, 38-40
occurrence and description of 24, 27-28, 36-37, 44
oil from 114, 117
possible overthrust in 28, 37-41, 44
section of 37
Katalla River, description of 17, 56
gas in 119
geology near 41, 44, 52
oil at 121
Katalla Slough, description of 53
oil near 114, 115, 117-118, 120-121
character of 122
test of 121
well near, oil from, analyses of 121-123
record of 120
Kayak, description of 20
geology near 46
Kayak Island, altitude of 58
description of 54, 57
fossils on 30, 38, 40
geology on 27, 38, 40-42, 44
topography of 15
view of 16
Kenai formation, fossils of 38, 39
Knowlton, F. H., fossils determined by 29, 34
on age of rocks 39
Kodiak, rocks at 27
Koyukuk River, coal on, analyses of 109, 110
Kushtaka formation, coal in 66
deposition of 63
fossils of 34-35, 38
occurrence and description of 24, 31-34, 36, 43
sections of 32-34, 37
Kushtaka Glacier, coal near 65
fossils near 36
location of 16
Kushtaka Lake, description of 56
fossils near 36
geology near 30, 42, 50, 52
Kushtaka Ridge, altitude of 58
coal near 65
analyses of 84-85, 87
sections of 73-76
fault on 43
fossils on 36
geology of 31, 35
section on 32-34

L.

Lake deposits, character of 52
Lakes, descriptions of 47-48, 49, 56
Land forms, description of 53-61
Latirus, occurrence of 36
Laube, F. E., work of 14

Page.
Leda, occurrence of 28, 29, 30, 31, 36
Leeper Creek, coal on, analyses of 84-85, 87
coal on, section of 77
Lignite, analyses of 110
bibliography of 129-133
distribution of 107
Limopsis, occurrence of 29
Liriodendron Meekii, occurrence of 29
Lisburne, Cape, coal at 107
coal at, analyses of 109
Litorina, occurrence of 28, 36
Lituya Bay, geology at 63
Lucina multilineata, occurrence of 36
Lunatia, occurrence of 28, 29, 30, 31, 36

M.

Macoma, occurrence of 28, 29, 30, 31, 36, 46
calcarea, occurrence of 30
McDonald, W. J., aid of 14
McPherson, J. L., maps by 11
Mactra, occurrence of 31, 34, 36
Maddren, A. G., aid of 13
Malaspina Glacier, character of 47, 49, 54
Map of Alaska, showing coal distribution 106
of Bering River coal field ..... Pocket.
of coast 10
of Controller Bay region ..... Pocket.
showing triangulation stations 12
Map, geologic, of Controller Bay region ..... Pocket.
Mapping, extent of 11
Marcia, occurrence of 28, 38
subdiaphana, occurrence of 30
Märjelen See, comparison with 48
Martin, G. C., work of 8, 10-11
Martin, Lawrence, work of 13
Martin River, description of 17
lakes on 56
oil near 116-117
Martin River Glacier, description of 16, 48-49
marginal lakes of 49
moraine of 49, 50-52
view of 16
Maryland, coal of, analysis of 111
Matanuska River, coal on 107
coal on, analysis of 109
geology on 115
Maxwell Creek, fossils on 31
Meadows, vegetation of 19
Mesozoic time, events of 61-62
Metamorphic rocks, occurrence and description of 26-27
Middleton Island, deposits of 52
Mining condition, discussion of 92-94, 108-109
Miocene rocks, deposition of 63
fossils in 39
occurrence of 40-41
Mirror Lake, character of 48
Mirror Slough, gas in 119
oil near 116-117
Mitcher Creek, fossils on 30
Modiolus, occurrence of 46
Mollusca, occurrence of 38, 39, 40
Molopophorus, occurrence of 36
Monument Mountain, coal near, analysis of 84-85, 87
coal near, section of 71
fossils near 36
Moraines, description of 47, 49, 50-52

Page.
Morrison Creek, oil on, analysis of..... 123
oil on, character of..... 122
Mount Campbell, altitude of..... 58
geology on..... 27, 52
topography near..... 15
Mount Hamilton, coal on, analyses of... 84-85, 87
coal on, sections of..... 80
geology of..... 35
Mount Nichawak. *See* Nichawak Mountain; Nichawak region.
Mount St. Elias—Yakutat Bay region, geology of..... 25-26
Mountains, character of..... 54
elevations of..... 15, 57-59
vegetation of..... 20
Mountain top, view of..... 16
Mulinia, occurrence of..... 29
Mya, occurrence of..... 28
arenaria, occurrence of..... 46
Mytilus, occurrence of..... 36

N.

Naphtha, consumption of, in Alaska..... 96, 98
Nassa, occurrence of..... 34, 36
Natica, occurrence of..... 30
Nation River, coal on, analyses of..... 109
Nenana River, lignite at, analyses of..... 110
Nevada Creek, coal on, analyses of..... 84-85, 87
coal on, section of..... 77
Neverita, occurrence of..... 28, 29, 30
New South Wales, coal of, analyses of..... 111
Nichawak region, geology of..... 27, 45
hills of..... 57
petroleum in..... 114, 118
Nichawak Mountain, altitude of..... 58
geology of..... 27, 52
oil near..... 118
topography near..... 15
Nichawak River, position of..... 56
Nuchek, climate at..... 18
Nucula, occurrence of..... 28

O.

Oil. *See* Petroleum.
Oil Creek, oil on, analysis of..... 123
oil on, character of..... 122
Okalee Spit, description of..... 54
geology of..... 53
Oligocene rocks, fossils of..... 38, 39, 40
occurrence of..... 40-41
Oliphant, F. H., on oil..... 121
Orca, climate at..... 18-19
rocks at..... 27
Orca Bay, harbor at..... 22
railway routes from..... 23-24
Orca series, age of..... 27
occurrence of..... 25
Oregon coal, analyses of..... 111
production of..... 99
Overthrust, occurrence and description of.. 26

P.

Pacific coals, analyses of..... 111
Pacific Coast region, coals of..... 107-108
Pacific Mountain system, description of.... 54
Paige, Sidney, work of..... 13

Page.
Pecten, occurrence of..... 28, 30
Penniman & Browne, analyses by..... 83-87, 121
Pennsylvania, coal of, analyses of..... 111
Periploma, occurrence of..... 28
Petricola, occurrence of..... 29
Petroleum, analyses of..... 121-123
bibliography of..... 130-133
character of..... 121-124
competition of, with coal..... 93-106
conclusions concerning..... 129-130
consumption of, in Alaska..... 96, 98
development of..... 113, 126-130
discovery of..... 14
efficiency of coal and..... 102-104
exploitation of..... 14, 129-130
geologic conditions of..... 112, 114-116, 124-126
locating of..... 126-127, 130
markets for..... 128-129
movement of..... 125
occurrences of..... 112, 113-114
descriptions of..... 116-121
map showing..... 113
requisites for..... 124-126
origin of..... 124
prices of..... 104-105
source of..... 116
structure and relations of..... 45-46, 114-116
supply of..... 105-106
tests of..... 121-123
transportation of..... 128-129
wells of..... 119-121, 127-128
Phacoides, occurrence of..... 28, 29
multilineata, occurrence of..... 29, 30
Philippines, coal of, analyses of..... 111
Phosphorus in coal, determination of..... 88
Physiography, description of..... 53-61
Pinnacle system, occurrence of..... 25
Pliocene rocks, occurrence of..... 63
Point Hey, fossils near..... 30
geology near..... 44
Popoff Island, geology on..... 39
Port Graham, lignite at, analysis of..... 110
Poul Creek, coal near, analysis of..... 84-85
oil on, analysis of..... 123
character of..... 122
Powers Creek, coal on, analyses of..... 84-85
section on..... 79
Precipitation, records of..... 17-19
Prince William Sound, region of, geology of. 25, 26
Proximate analysis, explanation of..... 89
Pseudamusium, occurrence of..... 30
Pteris frigida, occurrence of..... 35
Publications, list of..... 130-133
Puget, ——, exploration by..... 10
Purpura, occurrence of..... 28

Q.

Quaternary deposits, character of..... 24
deposition of..... 64-65
occurrence and description of..... 46, 50-53
Queen Creek, coal on, analyses of..... 84-85
coal on, sections of..... 76-77
geology at..... 43
Quercus, occurrence of..... 29, 35

R.

Page.
Ragged Mountain, coal near, chance of..... 66
elevation of..... 58
geology of..... 26, 42, 44, 61, 116
glaciers on..... 16
oil near..... 117
Railways, construction of..... 15, 21-24
possible routes for..... 23-24
Redwood, Sir Boverton, on oil..... 121-122
Redwood Creek, geology on..... 43-44, 118
oil at..... 114, 115, 117, 120
Relief, discussion of..... 57-61
Rivers, description of..... 16-17, 55-56
Rostellites, occurrence of..... 40
indurata, occurrence of..... 30
Russell, I. C., on Malaspina glacier..... 47, 48
on Yakutat Bay geology..... 26
Russians, explorations by..... 9-10, 14

S.

Saint Elias, Cape, geology of..... 42
Salix varians, occurrence of..... 35
Salmon canneries, establishment of..... 14
Sampling, methods of..... 83
San Francisco, coal market of..... 100
Sapindus, occurrence of..... 34
Saxicava, occurrence of..... 29
Saxidomus, occurrence of..... 31
Scala, occurrence of..... 28
Schizaster, occurrence of..... 29
Semele, occurrence of..... 30, 34
Semianthracite coal, analyses of..... 84-87, 109
area of..... 65
character of..... 81-82, 90-92
definition of..... 88-89
distribution of..... 90-92
Semibituminous coal, analyses of..... 84-87, 109
area of..... 65, 107
character of..... 81-82, 90-92, 112
definition of..... 88-89
distribution of..... 90-92
Serripes grönlandicus, occurrence of..... 46
Seton-Karr, H. W., exploration by..... 10
Sheep Creek, coal on, view of..... 92
fossils on..... 31, 35
Shepherd Creek, coal on, analyses of..... 84-85
coal on, section of..... 78
description of..... 17, 56
faults on..... 43
geology on..... 31, 43, 50, 52
Shockum Mountains, altitude of..... 58
geology at..... 30, 52
Shore line, character of..... 54-55
Shumagin Islands, geology of..... 63
Sills, occurrence and description of. 41, 70, 71, 72, 92
Sitka, climate at..... 18
Slope Glacier, description of..... 16, 49-50
Softuk Bar, description of..... 53
geology of..... 53
Solemya, occurrence of..... 29
Solen, occurrence of..... 28, 30, 31, 36
Spisula, occurrence of..... 28, 31, 34, 36
Spisula albaria, occurrence of..... 28
Split Creek, fossils on..... 28
geology on..... 43-44
Spondylus, occurrence of..... 30
Spruce, distribution of..... 19-20
Stanton, F. M., analyses by..... 83-87
Steamships, tests of coal and oil by..... 103
use of coal by..... 96-98
Stillwater Creek, description of..... 16-17, 56
fossils on..... 31
geology on..... 30, 41, 52
Stillwater formation, deposition of..... 63
fossils of..... 31, 38-40
occurrence and description of.. 24, 30, 36, 37, 43
overthrust in..... 43
section of..... 37
Stoess, P. C., on oil..... 122
Stone, R. W., aid of..... 13
Stratigraphy, description of..... 24-41, 46, 50-53
table of..... 24
Strawberry Harbor, oil at..... 117, 120
Strawberry Point, fossils near..... 30
geology of..... 53
Stream deposits, description of..... 52-53
Streams, descriptions of..... 16-17, 55-56
Structure, discussion of..... 42-46, 64
relation of petroleum and..... 45-46, 114-116
Subbituminous coal, analyses of..... 109
definition of..... 88
Suckling, Cape, description of..... 54
Suckling Hills, altitude of..... 58
character of..... 57
geology of..... 52
Sullivan, E. C., analyses by..... 83-87
Surveys, progress of..... 10-13
Swamps, vegetation of..... 19

T.

Tarr, R. S., on Yakutat Bay geology..... 26
Tebenkof, M. D., surveys by..... 10
Telegraph, extent of..... 20
Tellina, occurrence of..... 46
Temperature, records of..... 17-19
Terraces, levels of..... 60
occurrence and description of..... 59-60
Tertiary rocks, character of..... 24-25
correlation of..... 26-27, 37-41
fossils in..... 28-31, 34-36, 38-40
occurrence and description of..... 27-46, 62-64
Tertiary time, events of..... 62-64
Thracia, occurrence of..... 28, 29, 30
Thyasira, occurrence of..... 29
Tokun formation, deposition of..... 63
fossils of..... 36, 38-40
occurrence and description of. 24, 35-36, 43, 65-66
sections of..... 35-36, 37
Tokun Creek, coal on, analyses of..... 83-85
coal on, sections of..... 78, 79
Tokun Lake, coal near..... 65
coal near, sections of..... 78
description of..... 56
geology on..... 31, 35, 36
Topography, description of..... 15, 53-61
geology and, relations of..... 25
Trails, descriptions of..... 21
Trams, construction of..... 21
Travel, difficulties of..... 21
Transportation, development of..... 15, 20, 24, 94-95, 128-129
Triangulation stations, locations of..... 11-12
location of, map showing..... 12

Page.
Triassic time, history of..... 61
Trout Creek, coal on, analyses of..... 84-85, 87
coal on, coking of..... 82
sections of..... 72-73
fossils on..... 36
geology on..... 30
Turbo, occurrence of..... 28
Turritella, occurrence of..... 30
Tyonek, lignite at, analyses of..... 110

U.

Ulmus, occurrence of..... 35
Ultimate analyses, meaning of..... 89
Unga Island, fossils of..... 39
lignite on, analyses of..... 110
Unio, occurrence of..... 30
United States Naval Liquid Fuel board, report of..... 102-103, 105
Uplift, occurrence of..... 64

V.

Valdez series, occurrence of..... 25
Valleys, occurrence and description of..... 60-61
Vancouver, George, explorations by..... 10
Vancouver Island, coal production of..... 99
Vegetation, character of..... 19-20
Venericardia ventricosa, occurrence of..... 29
Volcanic vents, evidence of..... 61
Volcanic plug, view of..... 16

W.

Page.
Wainwright Inlet, lignite at, analyses of... 110
Washington coal, analyses of..... 111
production of..... 99
Water, underground, occurrence of..... 94
Weaver, C. E., aid of..... 13
Wells, oil, description of..... 119-121
drilling of..... 127-128
West Virginia, coal of, analyses of..... 111
Whale Island, harbor at..... 15, 22
Wingham Island, character of..... 57
fossils on..... 30, 46
geology of..... 26, 27, 38, 42, 44, 46, 51, 61, 64, 116
topography of..... 15

Y.

Yakataga. (*See* Yaktag.)
Yaktag region, geology near..... 26, 63, 115
oil near..... 114, 118
Yakutat, rocks at..... 27
Yakutat Bay—Mount St. Elias region, geology of..... 25-26
Yakutat system, occurrence of..... 25
Yoldia, occurrence of..... 28, 29, 30, 33, 36
montereyensis, occurrence of..... 30
scissurata, occurrence of..... 30
thraciaformis, occurrence of..... 30
Yukon basin, coal in..... 107
coal in, analyses of..... 109, 110

RECENT SURVEY PUBLICATIONS ON ALASKA.

[Arranged geographically. A complete list can be had on application.]

All of these publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except certain maps), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries throughout the United States, where they can be consulted by those interested.

GENERAL.

The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate by Cleveland Abbe, jr., and a topographic map and description thereof, by R. U. Goode. Professional Paper No. 45, 1906, 327 pp.

Placer mining in Alaska in 1904, by A. H. Brooks. In Bulletin No. 259, 1905, pp. 18–31.

The mining industry in 1905, by A. H. Brooks. In Bulletin No. 284, 1906, pp. 4–9.

The mining industry in 1906, by A. H. Brooks. In Bulletin No. 314, 1907, pp. 19–39.

Railway routes, by A. H. Brooks. In Bulletin No. 284, 1906, pp. 10–17.

Administrative report, by A. H. Brooks. In Report on progress of investigations of mineral resources of Alaska in 1904: Bulletin No. 259, 1905, pp. 13–17.

Administrative report, by A. H. Brooks. In Report on progress of investigations of mineral resources of Alaska in 1905: Bulletin No. 284, 1906, pp. 1–3.

Administrative report, by A. H. Brooks. In Report on progress of investigations of mineral resources of Alaska in 1906: Bulletin No. 314, 1907, pp. 11–18.

Notes on the petroleum fields of Alaska, by G. C. Martin. In Bulletin No. 259, 1905, pp. 128–139.

The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. Bulletin No. 250, 1905, 64 pp.

Markets for Alaska coal, by G. C. Martin. In Bulletin No. 284, 1906, pp. 18–29.

The Alaska coal fields, by G. C. Martin. In Bulletin No. 314, 1907, pp. 40–46.

Methods and costs of gravel and placer mining in Alaska, by C. W. Purington. Bulletin No. 263, 1905, 362 pp. (Out of stock; can be purchased from Superintendent of Documents, Washington, D. C., for 35 cents.) Abstract in Bulletin No. 259, 1905, pp. 32–46.

Geographic dictionary of Alaska, by Marcus Baker, second edition by J. C. McCormick. Bulletin No. 299, 1906, 690 pp.

Topographic map.

Alaska, topographic map of; scale, 1:2500000. Preliminary edition by R. U. Goode. Contained in Professional Paper No. 45. Not published separately.

In preparation.

Methods and costs of gravel and placer mining in Alaska, by C. W. Purington. Second edition.

Map of Alaska; scale, 1:5000000; by A. H. Brooks.

SOUTHEASTERN ALASKA.

Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by Alfred H. Brooks. Professional Paper No. 1, 1902, 120 pp.

The Porcupine placer district, Alaska, by C. W. Wright. Bulletin No. 236, 1904, 35 pp.
The Treadwell ore deposits, by A. C. Spencer. In Bulletin No. 259, 1905, pp. 69–87.
Economic developments in southeastern Alaska, by F. E. and C. W. Wright. In Bulletin No. 259, 1905, pp. 47–68.
The Juneau gold belt, Alaska, by A. C. Spencer, pp. 1–137, and A reconnaissance of Admiralty Island, Alaska, by C. W. Wright, pp. 138–154. Bulletin No. 287, 1906, 161 pp.
Lode mining in southeastern Alaska, by F. E. and C. W. Wright. In Bulletin No. 284, 1906, pp. 30–53.
Nonmetallic deposits of southeastern Alaska, by C. W. Wright. In Bulletin 284, 1906, pp. 54–60.
The Yakutat Bay region, by R. S. Tarr. In Bulletin No. 284, 1906, pp. 61–64.
Lode mining in southeastern Alaska, by C. W. Wright. In Bulletin No. 314, 1907, pp. 47–72.
Nonmetalliferous mineral resources of southeastern Alaska, by C. W. Wright. In Bulletin No. 314, 1907, pp. 73–81.
Reconnaissance on the Pacific coast from Yakutat to Alsek River, by Eliot Blackwelder. In Bulletin No. 314, 1907, pp. 82–88.

Topographic maps.

Juneau Special quadrangle; scale, 1:62500; by W. J. Peters. For sale at 5 cents each, or $3 per hundred.
Topographic map of the Juneau gold belt, Alaska. Contained in Bulletin 287, Plate XXXVI, 1906. Not issued separately.

In preparation.

Report on progress of investigations of mineral resources of Alaska in 1907, by Alfred H. Brooks and others. 1908. — pp., — pls.
Physiography and glacial geology of the Yakutat Bay region, Alaska, by R. S. Tarr, with a chapter on the bed-rock geology by R. S. Tarr and B. S. Butler.
The Ketchikan and Wrangell mining districts, Alaska, by F. E. and C. W. Wright.
Berners Bay Special map; scale, 1:62500; by R. B. Oliver. (In press.)
Kasaan Peninsula Special map; scale, 1:62500; by D. C. Witherspoon and J. W. Bagley.

CONTROLLER BAY, PRINCE WILLIAM SOUND, AND COPPER RIVER REGIONS.

The mineral resources of the Mount Wrangell district, Alaska, by W. C. Mendenhall. Professional Paper No. 15, 1903, 71 pp. Contains general map of Prince William Sound and Copper River region; scale, 12 miles = 1 inch. (Out of stock; can be purchased from Superintendent of Documents for 30 cents.)
Bering River coal field, by G. C. Martin. In Bulletin No. 259, 1905, pp. 140–150.
Cape Yaktag placers, by G. C. Martin. In Bulletin No. 259, 1905, pp. 88–89.
Notes on the petroleum fields of Alaska, by G. C. Martin. In Bulletin No. 259, 1905, pp. 128–139. Abstract from Bulletin No. 250.
The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. Bulletin No. 250, 1905, 64 pp.
Geology of the central Copper River region, Alaska, by W. C. Mendenhall. Professional Paper No. 41, 1905, 133 pp.
Copper and other mineral resources of Prince William Sound, by U. S. Grant. In Bulletin No. 284, 1906, pp. 78–87.
Distribution and character of the Bering River coal, by G. C. Martin. In Bulletin No. 284, 1906, pp. 65–76.
Petroleum at Controller Bay, by G. C. Martin. In Bulletin No. 314, 1907, pp. 89–103.
Geology and mineral resources of Controller Bay region, by G. C. Martin. Bulletin No. 335, 1908, 141 pp.

Topographic maps.

Map of Mount Wrangell; scale, 12 miles = 1 inch. Contained in Professional Paper No. 15. Not issued separately.
Copper and upper Chistochina rivers; scale, 1:250000; by T. G. Gerdine. Contained in Professional Paper No. 41. Not issued separately.
Copper, Nabesna, and Chisana rivers, headwaters of; scale, 1:250000. D. C. Witherspoon. Contained in Professional Paper No. 41. Not issued separately.

Controller Bay region Special map; scale, 1:62500; by E. G. Hamilton. For sale at 35 cents a copy or $21.00 per hundred.
General map of Alaska coast region from Yakutat Bay to Prince William Sound; scale, 1:1200000; compiled by G. C. Martin. Contained in Bulletin No. 335.

In preparation.

The Kotsina-Chitina copper region, by F. H. Moffit.
Chitina quadrangle map; scale, 1:250000; by T. G. Gerdine and D. C. Witherspoon.

COOK INLET AND SUSITNA REGION.

The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. Bulletin No. 250, 1905, 64 pp.
Coal resources of southwestern Alaska, by R. W. Stone. In Bulletin No. 259, 1905, pp. 151–171.
Gold placers of Turnagain Arm, Cook Inlet, by F. H. Moffit. In Bulletin No. 259, 1905, pp. 90–99.
Mineral resources of the Kenai Peninsula; Gold fields of the Turnagain Arm region, by F. H. Moffit, pp. 1–52; Coal fields of the Kachemak Bay region, by R. W. Stone, pp. 53–73. Bulletin No. 277, 1906, 80 pp.
Preliminary statement on the Matanuska coal field, by G. C. Martin. In Bulletin No. 284, 1906, pp. 88–100.
A reconnaissance of the Matanuska coal field, Alaska, in 1905, by G. C. Martin. Bulletin No. 289, 1906, 36 pp. (Out of stock; can be purchased of Superintendent of Documents for 25 cents.)
Reconnaissance in the Matanuska and Talkeetna basins, by S. Paige and A. Knopf. In Bulletin No. 314, 1907, pp. 104–125.
Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska, by S. Paige and A. Knopf. Bulletin No. 327, 1907, 71 pp.

Topographic maps.

Kenai Peninsula, northern portion; scale, 1:250000; by E. G. Hamilton. Contained in Bulletin No. 277. Not published separately.
Reconnaissance map of Matanuska and Talkeetna region; scale, 1:250000; by T. G. Gerdine and R. H. Sargent. Contained in Bulletin No. 327. Not published separately.
Mount McKinley region; scale, 1:625000; by D. L. Reaburn. Contained in Professional Paper No. 45. Not published separately.

ALASKA PENINSULA AND ALEUTIAN ISLANDS.

Gold mine on Unalaska Island, by A. J. Collier. In Bulletin No. 259, 1905, pp. 102–103.
Gold deposits of the Shumagin Islands, by G. C. Martin. In Bulletin No. 259, 1905, pp. 100–101.
Notes on the petroleum fields of Alaska, by G. C. Martin. In Bulletin No. 259, 1905, pp. 128–139. Abstract from Bulletin No. 250.
The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. In Bulletin No. 250, 1905, 64 pp.
Coal resources of southwestern Alaska, by R. W. Stone. In Bulletin No. 259, 1905, pp. 151–171.
The Herendeen Bay coal field, by Sidney Paige. In Bulletin No. 284, 1906, pp. 101–108.

YUKON BASIN.

The coal resources of the Yukon, Alaska, by A. J. Collier. Bulletin No. 218, 1903, 71 pp.
The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, by L. M. Prindle. Bulletin No. 251, 1905, 89 pp.
Yukon placer fields, by L. M. Prindle. In Bulletin No. 284, 1906, pp. 109–131.
Reconnaissance from Circle to Fort Hamlin, by R. W. Stone. In Bulletin No. 284, 1906, pp. 128–131.
The Yukon-Tanana region, Alaska; description of the Circle quadrangle, by L. M. Prindle. Bulletin No. 295, 1906, 27 pp.
The Bonnifield and Kantishna regions, by L. M. Prindle. In Bulletin No. 314, 1907, pp. 205–226.

The Circle Precinct, Alaska, by Alfred H. Brooks. In Bulletin No. 314, 1907, pp. 187–204.

The Yukon-Tanana region, Alaska; description of the Fairbanks and Rampart quadrangles, by L. M. Prindle, F. L. Hess, and C. C. Covert. Bulletin No. 337, 1908, — pp.

Topographic maps.

Fortymile quadrangle; scale, 1:250000; by E. C. Barnard. For sale at 5 cents a copy or $3 per hundred.

Yukon-Tanana region, reconnaissance map of; scale, 1:625000; by T. G. Gerdine. Contained in Bulletin No. 251, 1905. Not published separately.

Fairbanks and Birch Creek districts, reconnaissance maps of; scale, 1:250000; by T. G. Gerdine. Contained in Bulletin No. 251, 1905. Not issued separately.

Circle quadrangle, Yukon-Tanana region; scale, 1:250000; by D. C. Witherspoon. Contained in Bulletin No. 295. Not issued separately.

In preparation.

Water-supply investigations in Alaska, 1906 and 1907, by F. F. Henshaw and C. C. Covert.

Fairbanks quadrangle map; scale, 1:250000; by D. C. Witherspoon. Contained in Bulletin No. 337, 1908.

Rampart quadrangle map; scale, 1:250000; by D. C. Witherspoon. Contained in Bulletin No. 337, 1908.

Fairbanks Special map; scale, 1:62500; by T. G. Gerdine and R. H. Sargent.

SEWARD PENINSULA.

A reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, Alaska, in 1900, by A. H. Brooks, G. B. Richardson, and A. J. Collier. In a special publication entitled "Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900," 1901, 180 pp.

A reconnaissance in the Norton Bay region, Alaska, in 1900, by W. C. Mendenhall. In a special publication entitled "Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900."

A reconnaissance of the northwestern portion of Seward Peninsula, Alaska, by A. J. Collier. Professional Paper No. 2, 1902, 70 pp.

The tin deposits of the York region, Alaska, by A. J. Collier. Bulletin No. 229, 1904, 61 pp.

Recent developments of Alaskan tin deposits, by A. J. Collier. In Bulletin No. 259, 1905, pp. 120–127.

The Fairhaven gold placers of Seward Peninsula, by F. H. Moffit. Bulletin No. 247, 1905, 85 pp.

The York tin region, by F. L. Hess. In Bulletin No. 284, 1906, pp. 145–157.

Gold mining on Seward Peninsula, by F. H. Moffit. In Bulletin No. 284, 1906, pp. 132–141.

The Kougarok region, by A. H. Brooks. In Bulletin No. 314, 1907, pp. 164–181.

Water Supply of Nome region, Seward Peninsula, Alaska, 1906, by J. C. Hoyt and F. F. Henshaw. Water-Supply Paper No. 196, 1907, 52 pp. (Out of stock; can be purchased of Superintendent of Documents for 15 cents.)

Water supply of the Nome region, Seward Peninsula, 1906, by J. C. Hoyt and F. F. Henshaw. In Bulletin No. 314, 1907, pp. 182–186.

The Nome region, by F. H. Moffit. In Bulletin No. 314, 1907, pp. 126–145.

Gold fields of the Solomon and Niukluk river basins, by P. S. Smith. In Bulletin No. 314, 1907, pp. 146–156.

Geology and mineral resources of Iron Creek, by P. S. Smith. In Bulletin No. 314, 1907, pp. 157–163.

The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougarok, Port Clarence, and Goodhope precincts, by A. J. Collier, F. L. Hess, P. S. Smith, and A. H. Brooks. Bulletin No. 328, 1908, 343 pp.

Topographic maps.

The following maps are for sale at *5 cents a copy*, or $3 per hundred:

Casadepaga quadrangle, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.

Grand Central Special, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.

Nome Special, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.
Solomon Special quadrangle, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.

The following maps are for sale at *25 cents a copy*, or $15 per hundred:

Seward Peninsula, northeastern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.
Seward Peninsula, northwestern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.
Seward Peninsula, southern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.

In preparation.

Water-supply investigations in Alaska, 1906 and 1907, by F. F. Henshaw and C. C. Covert.
Geology of the area represented on the Nome and Grand Central Special maps, by F. H. Moffit, F. L. Hess, and P. S. Smith.
Geology of the area represented on the Solomon and Casadepaga Special maps, by P. S. Smith.
The Seward Peninsula tin deposits, by A. Knopf.

NORTHERN ALASKA.

A reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. Professional Paper No. 10, 1902, 68 pp.
A reconnaissance in northern Alaska across the Rocky Mountains, along the Koyukuk, John, Anaktuvuk, and Colville rivers, and the Arctic coast to Cape Lisburne, in 1901, by F. C. Schrader and W. J. Peters. Professional Paper No. 20, 1904, 139 pp. (Out of stock; can be purchased of Superintendent of Documents for 40 cents.)
Coal fields of the Cape Lisburne region, by A. J. Collier. In Bulletin No. 259, 1905, pp. 172–185.
Geology and coal resources of Cape Lisburne region, Alaska, by A. J. Collier. Bulletin No. 278, 1906, 54 pp.

Topographic maps.

Fort Yukon to Kotzebue Sound, reconnaissance map of; scale, 1:625000; by D. L. Reaburn. Contained in Professional Paper No. 10. Not published separately.
Koyukuk River to mouth of Colville River, including John River; scale, 1:625000; by W. J. Peters. Contained in Professional Paper No. 20. (Out of stock.) Not published separately.

O

Ir
Sc
On
Pl
S Bi

A

Lo

A

Th